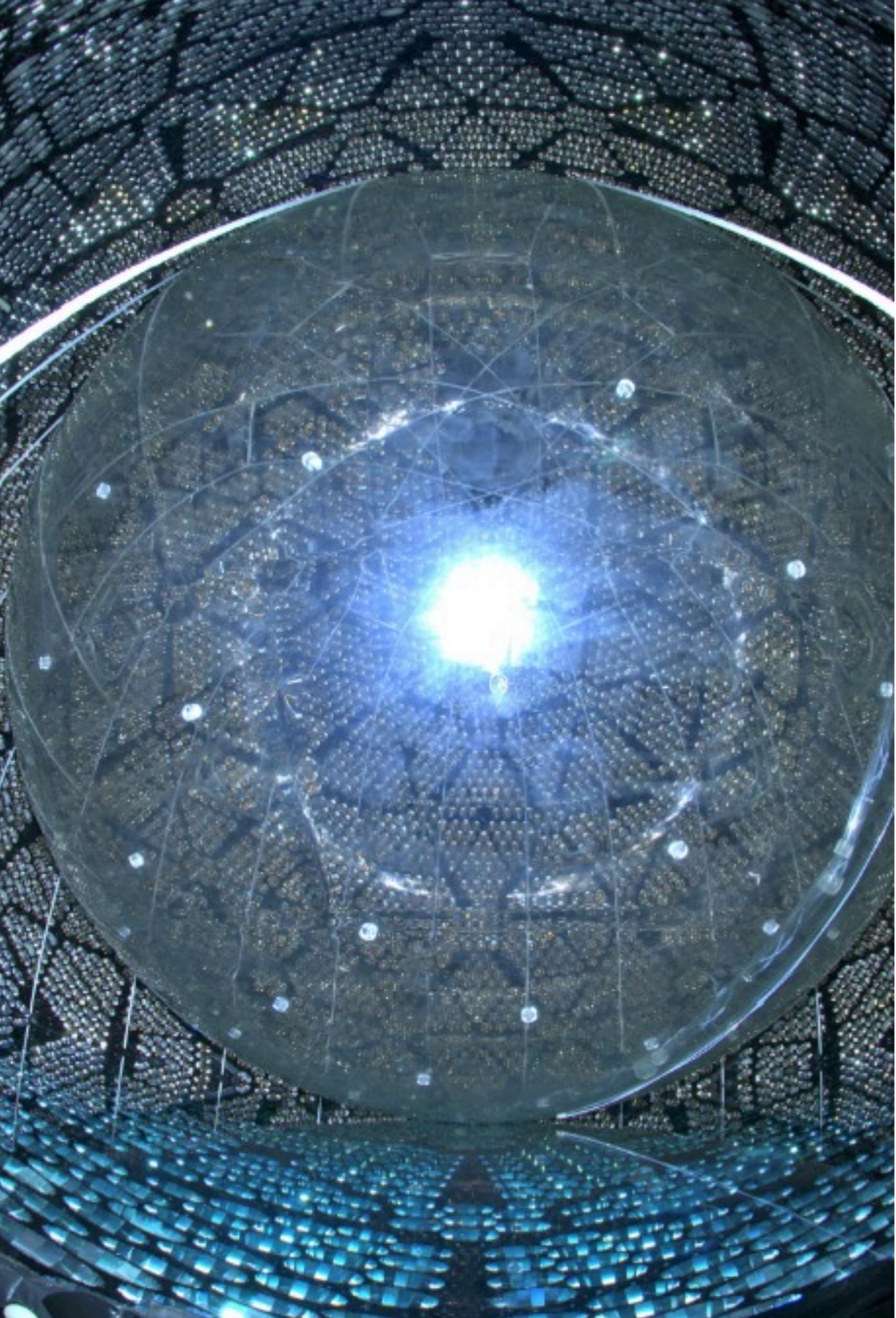


SNO+ & THEIA

Te-loaded LS Detectors

For NDBD and Other Physics

Gabriel D. Orebi Gann
UC Berkeley & LBNL



SNO+

- Re-use SNO detector
 - ▶ 12-m diameter acrylic vessel
 - ▶ ~9500 PMTs
 - Replace D₂O with liquid scintillator (LAB)
 - New hold-down rope net
 - 7kT H₂O buffer
 - Load LAB with 0.3% ^{nat}Te
- ➡ **NDBD search**

Advantages of LS approach

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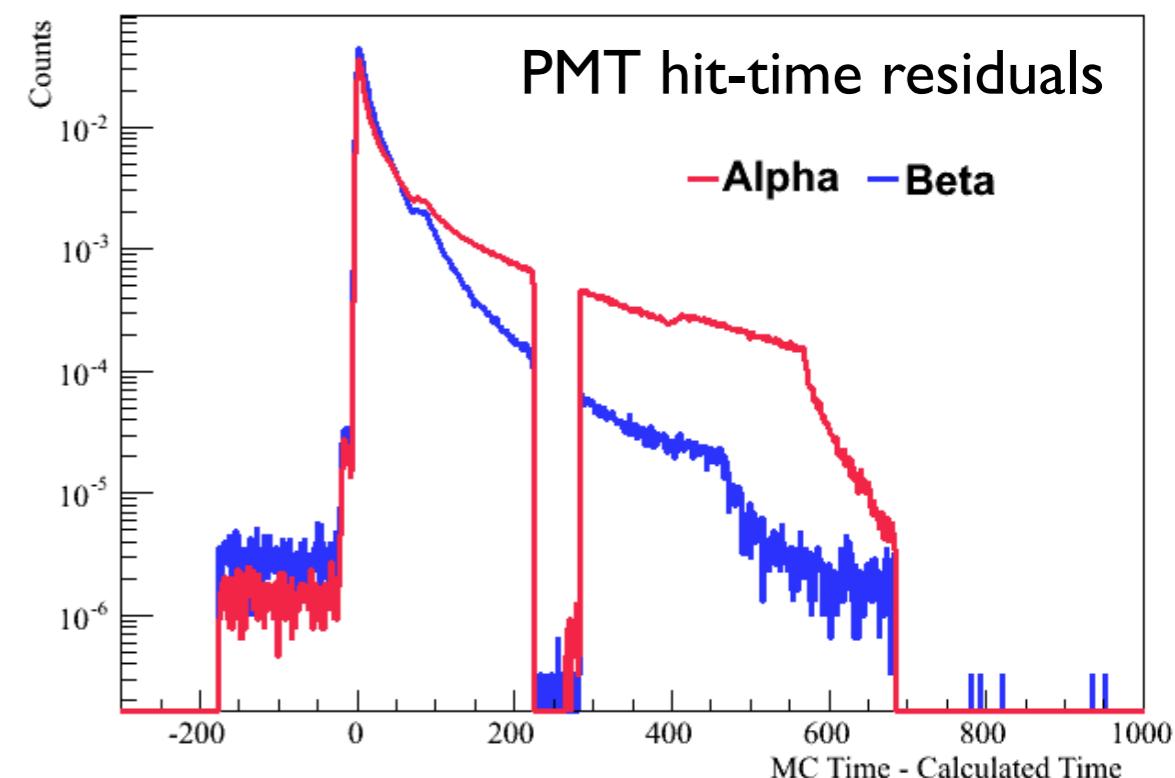
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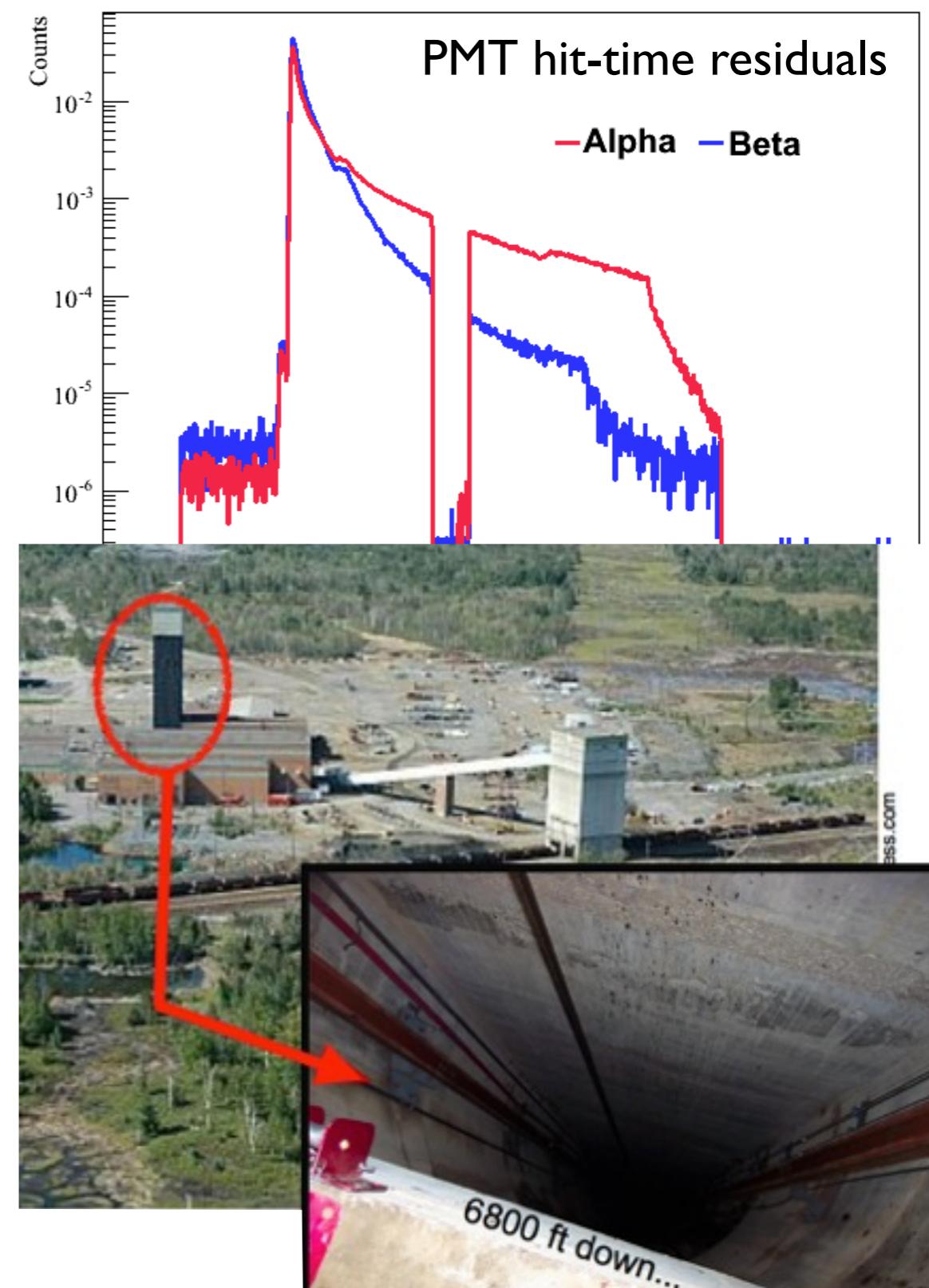
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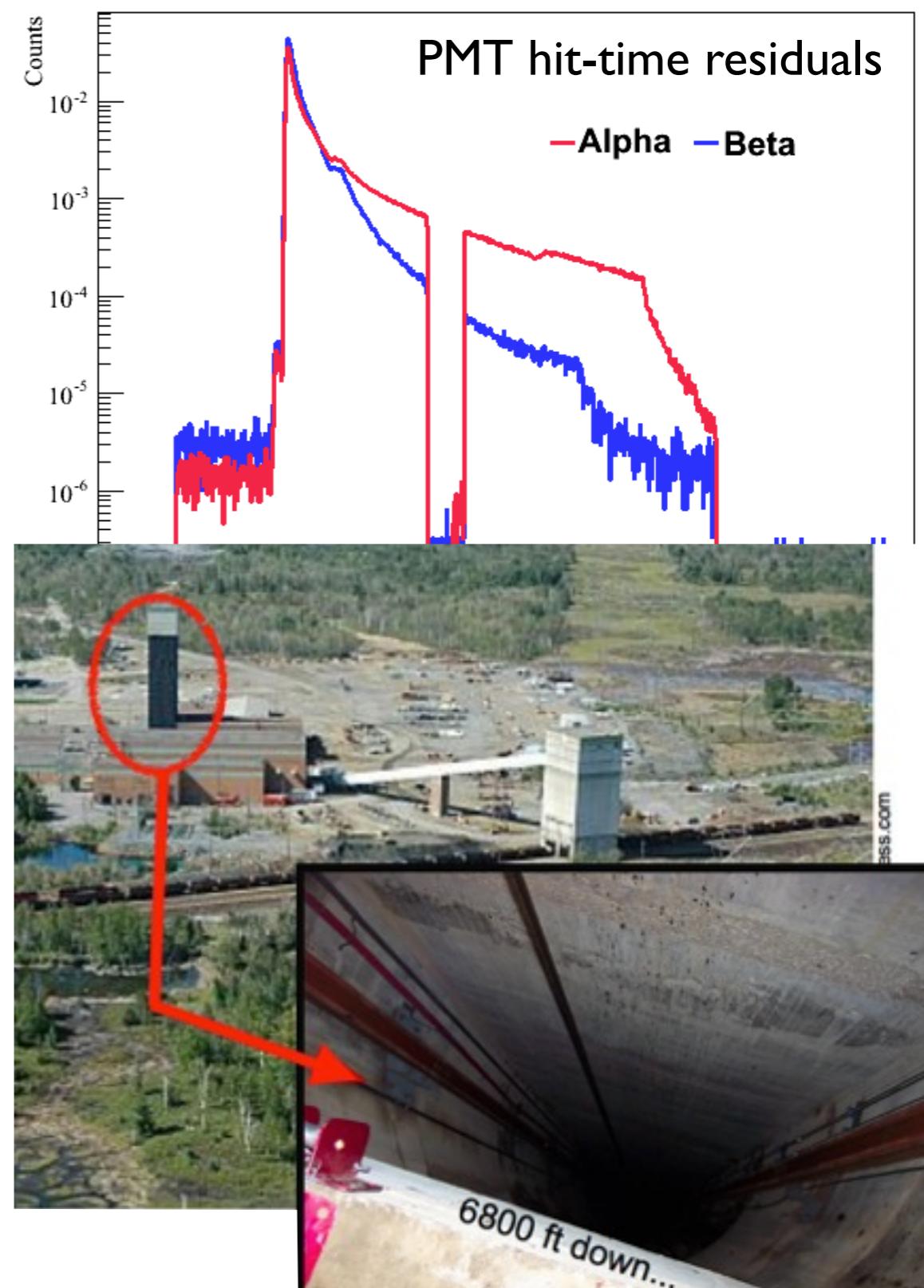
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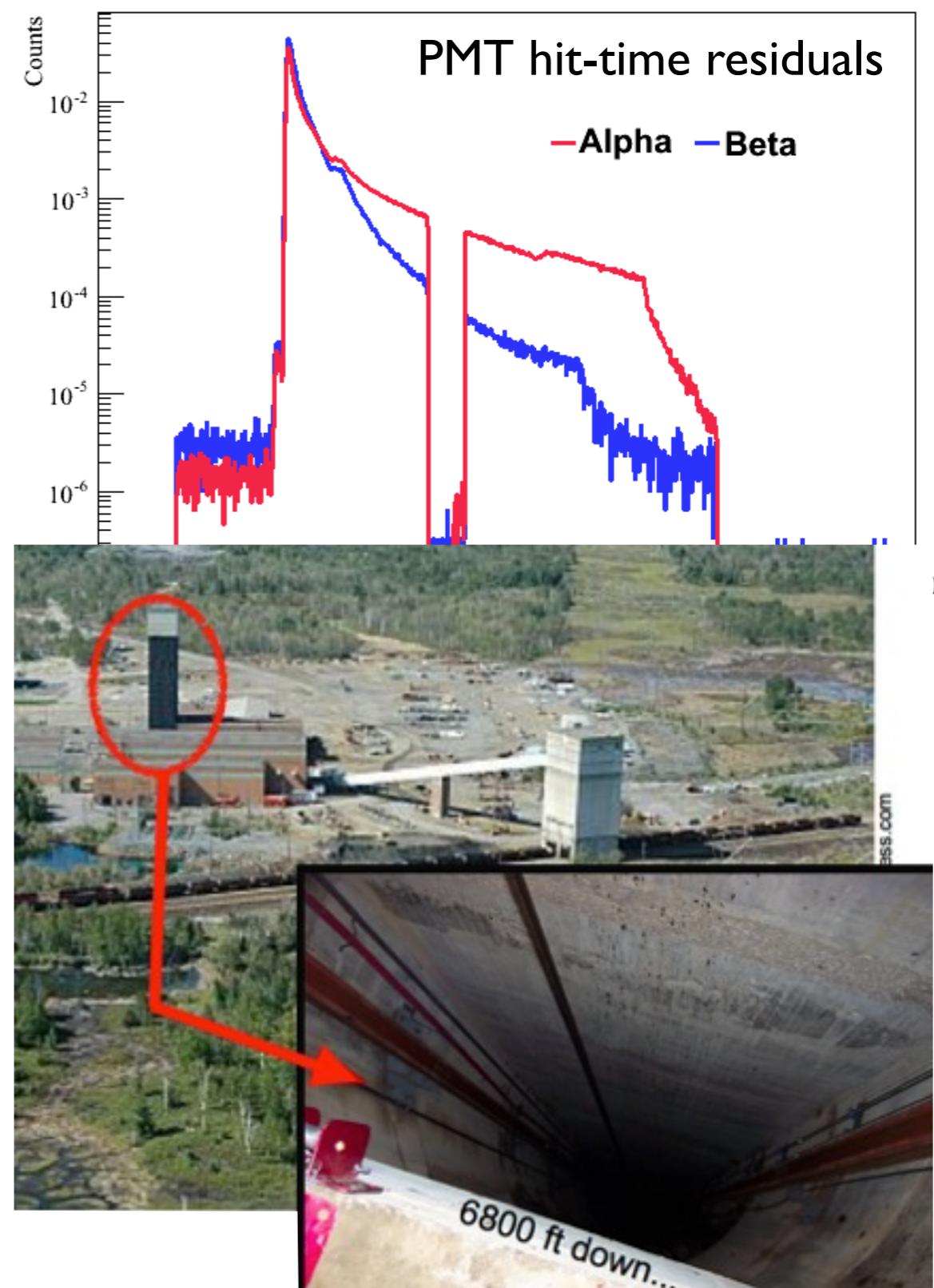
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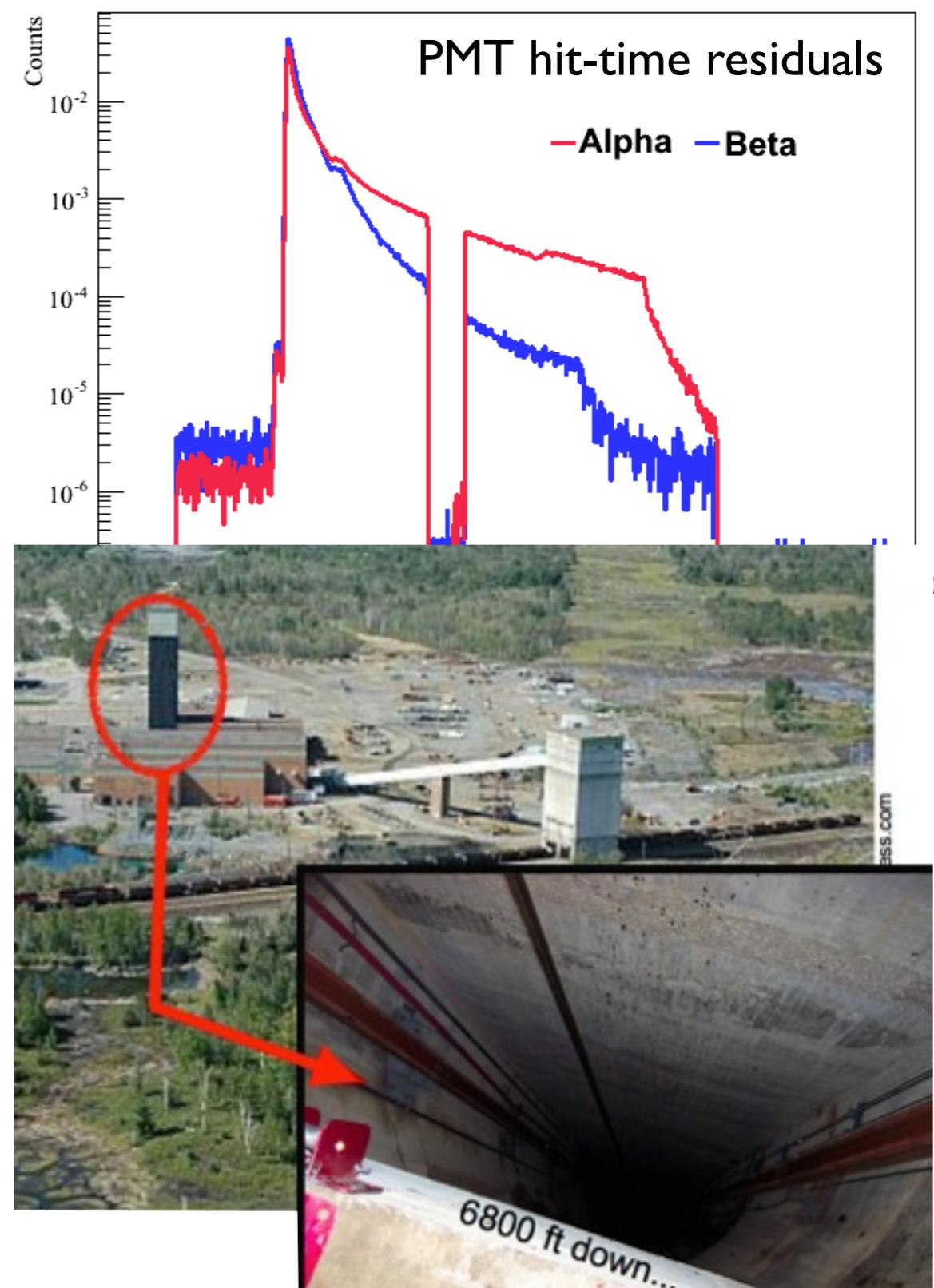
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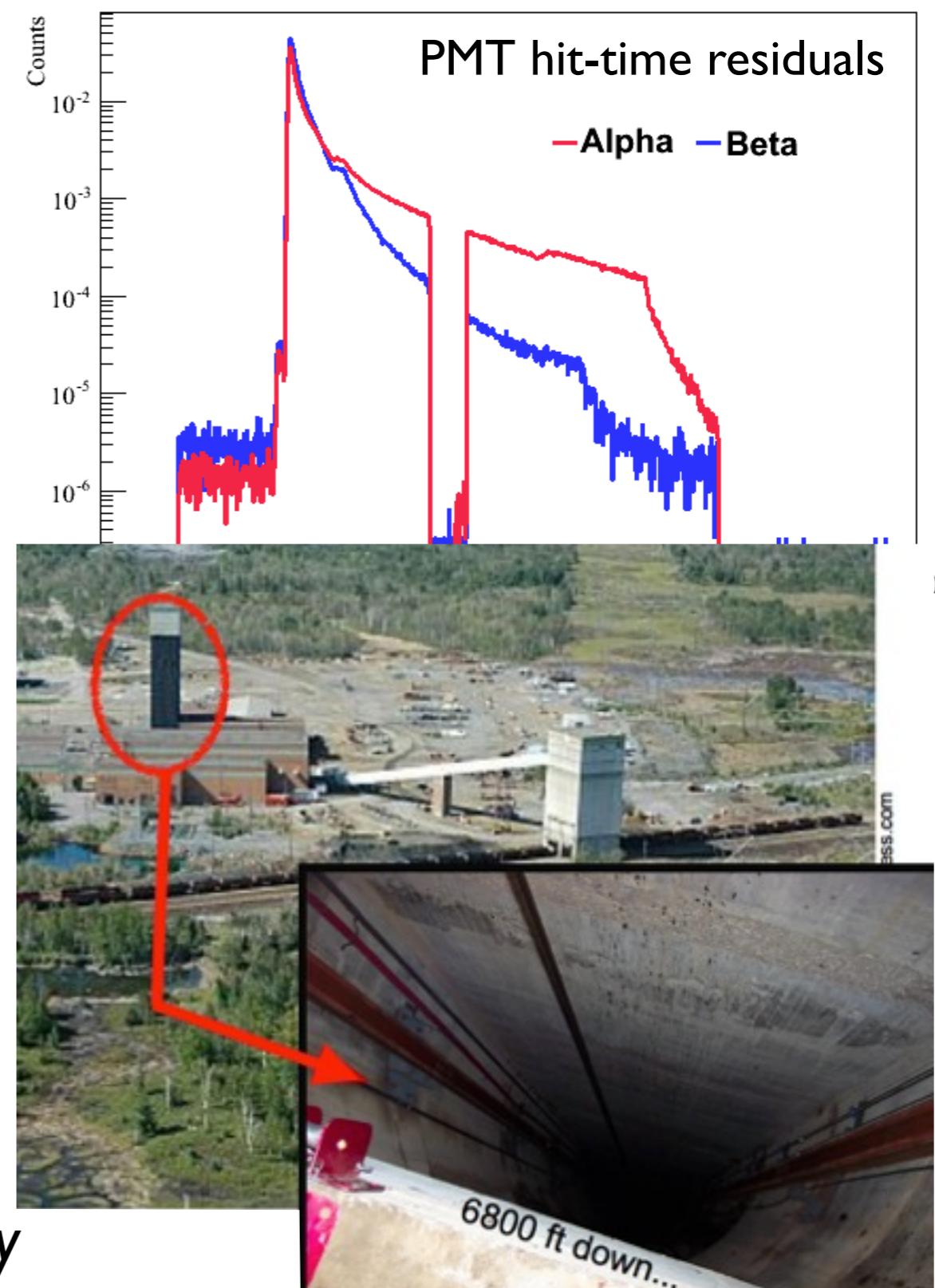
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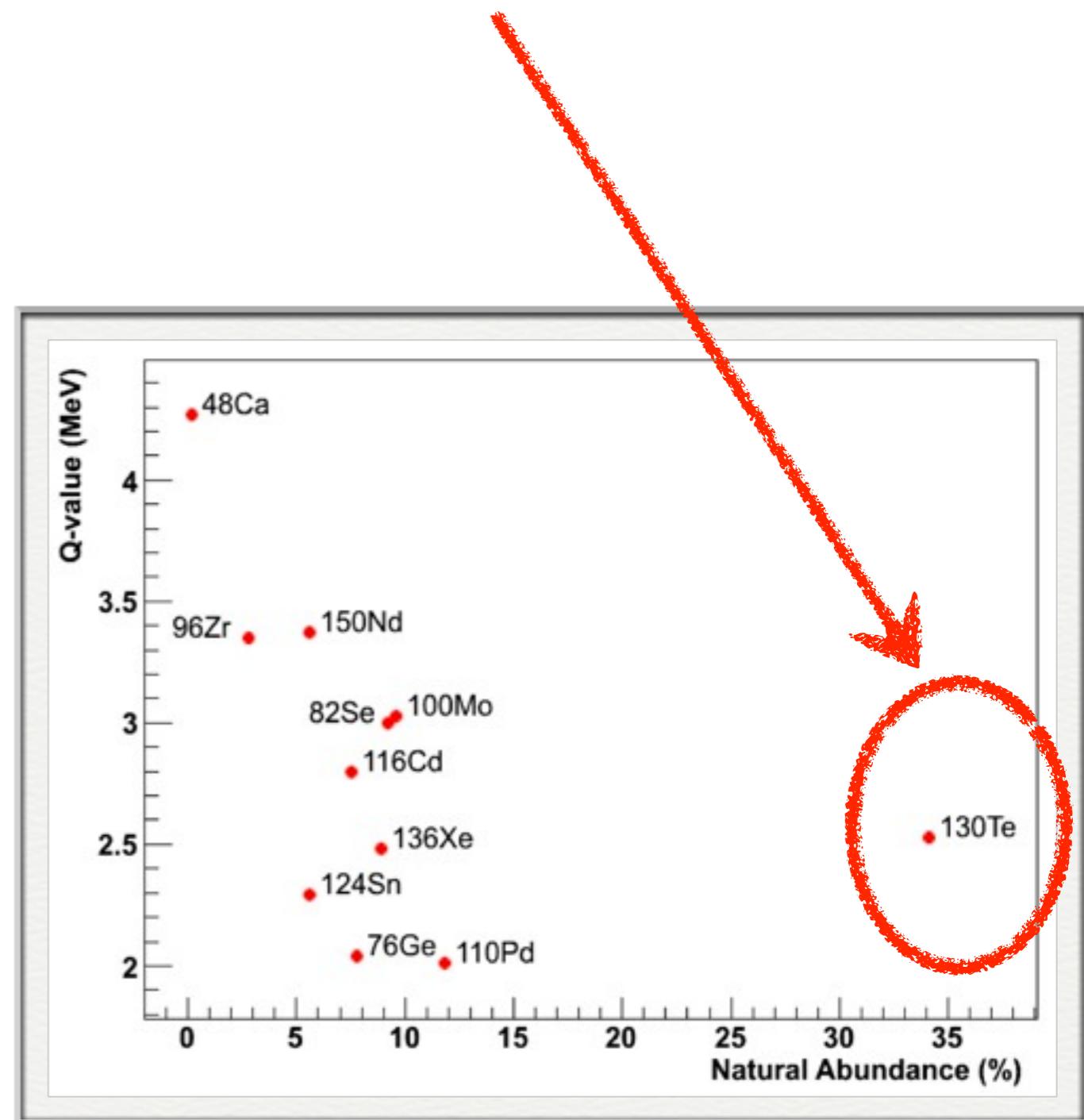
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- *Bonus: broad program includes solar, geo, reactor, supernova ν & nucleon decay*

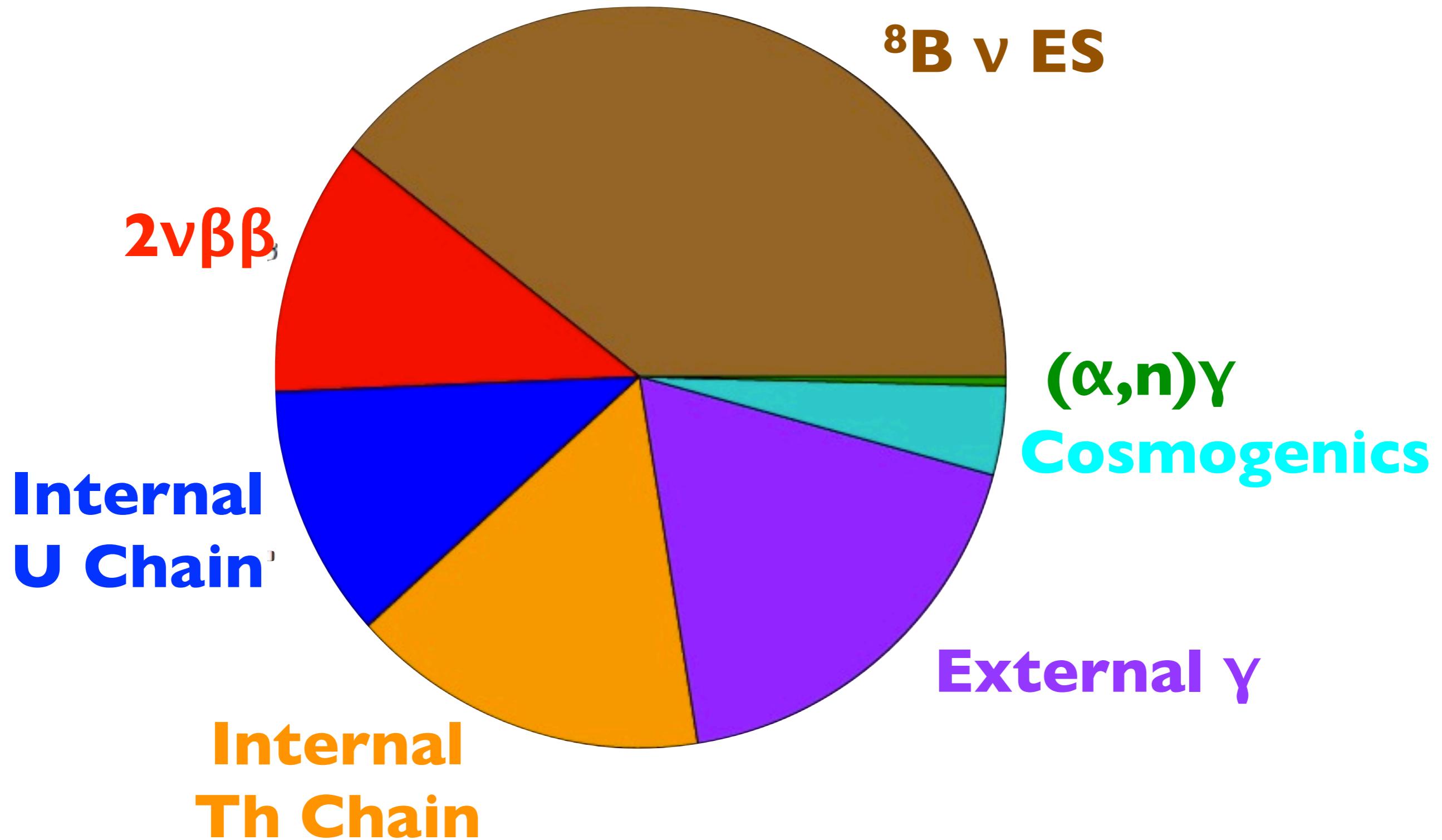


Advantages of ^{130}Te

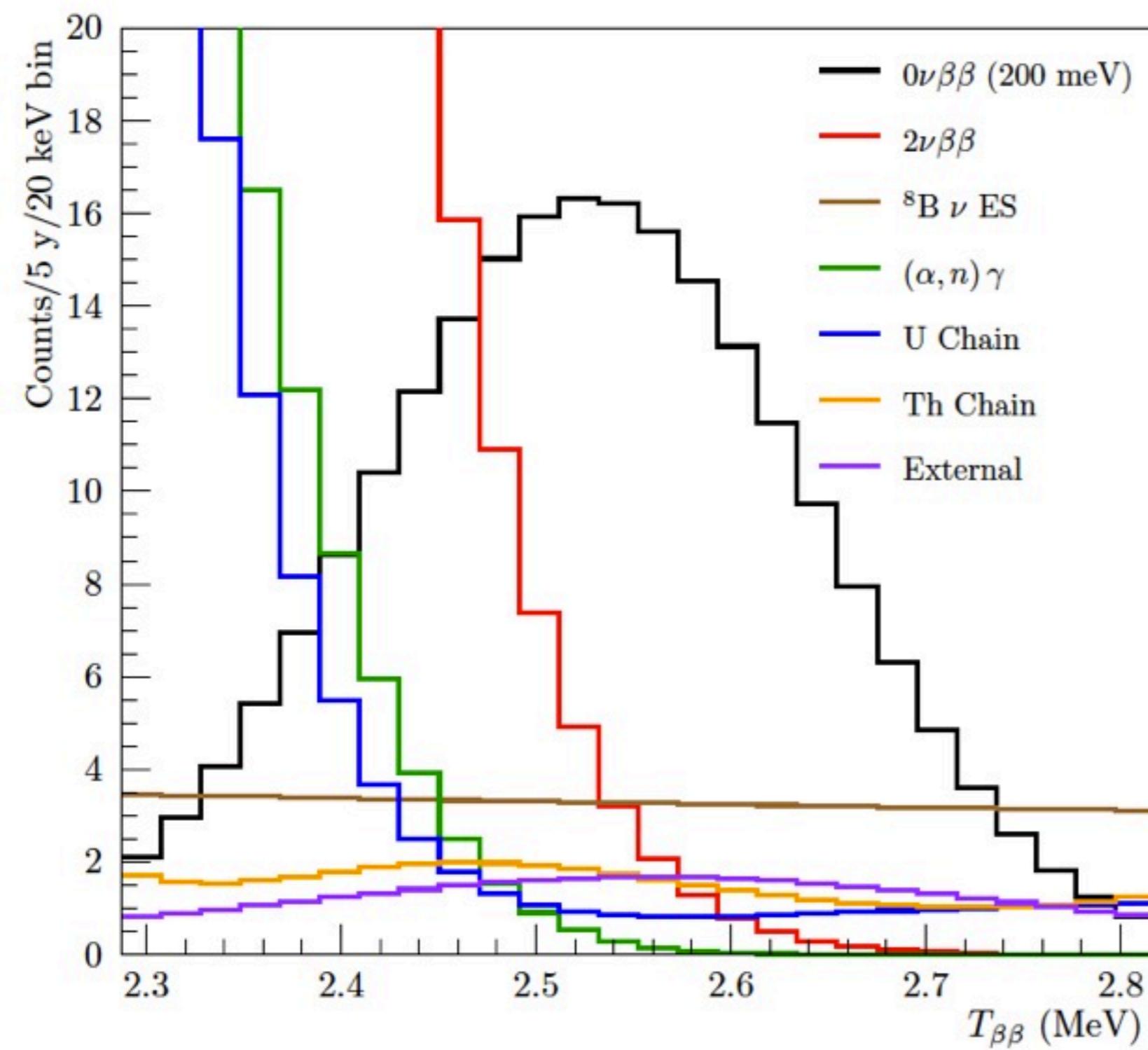
- ❖ High natural abundance
⇒ high loading w/o enrichment
- ❖ Favourable $2\nu\beta\beta:0\nu\beta\beta$ (less sensitive to poor E resn)
- ❖ R/A background rejection at 99.9% (coincidence tag) at endpoint (2.53 MeV)
- ❖ Good optical properties
 - ❖ High intrinsic γ yield
 - ❖ No abs. peaks



SNO+ Background Budget

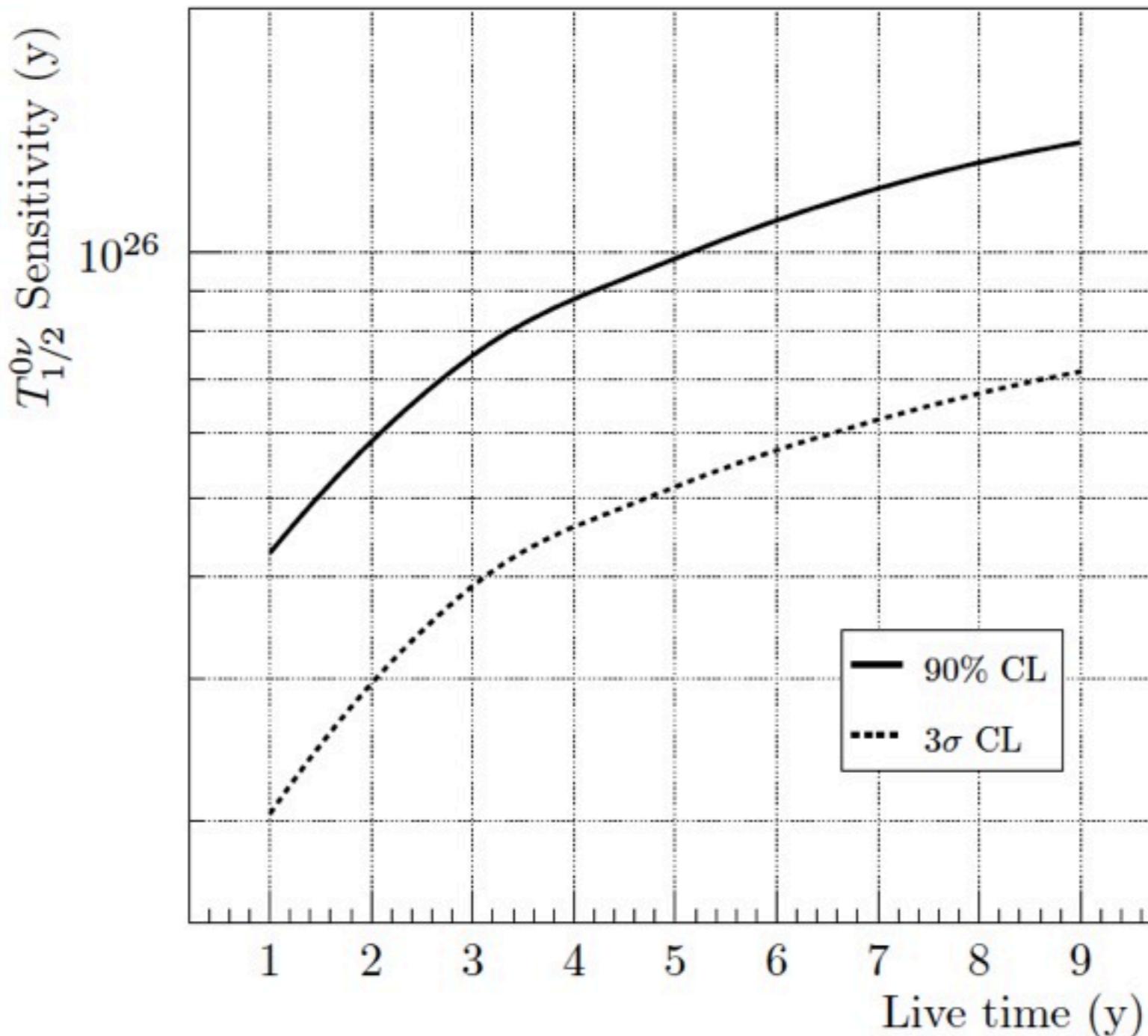


SNO+ Spectrum



- **Assumptions:**
 - NME = 4.03 (IBM-2)
 - $G = 3.69 \times 10^{-14} /y$ ($g_A = 1.269$)
 - 0.3% natural Te
 - 5 years live time
 - Optics from ex-situ (Penn/BNL)
 - 3.5m fiducial volume (20%)
 - 100% detection efficiency
 - Background rejection efficiencies
 - AV/PMT r/a at SNO-proposal levels

SNO+ Sensitivity



1 yrs @ 0.3% loading: $\sim 4.3 \times 10^{25}$ yrs (~ 100 meV)

5 yrs @ 0.3% loading: $\sim 9.7 \times 10^{25}$ yrs (~ 67 meV)

SNO+ Status

- Filling detector with water now
- Water-filled data summer 2015:
nucleon decay, external backgrounds
- LS fill due to commence late 2015
- LS data 2016:
solar, reactor, geo, S/N, LS backgrounds
- Te loading: 2016 (0.3%)

Upgrade Paths

Upgrading from version 1.0 to 2.0

Upgrading from version 2.0 to 3.0

Upgrading from version 3.0 to 4.0

Upgrading from version 4.0 to 5.0

Upgrading from version 5.0 to 6.0

Upgrading from version 6.0 to 7.0

Upgrading from version 7.0 to 8.0

Upgrading from version 8.0 to 9.0

Upgrading from version 9.0 to 10.0

Upgrading from version 10.0 to 11.0

Upgrading from version 11.0 to 12.0

Upgrading from version 12.0 to 13.0

Upgrading from version 13.0 to 14.0

Upgrading from version 14.0 to 15.0

Upgrading from version 15.0 to 16.0

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- SNO+ 0.3% run: prototype for multi-T experiment

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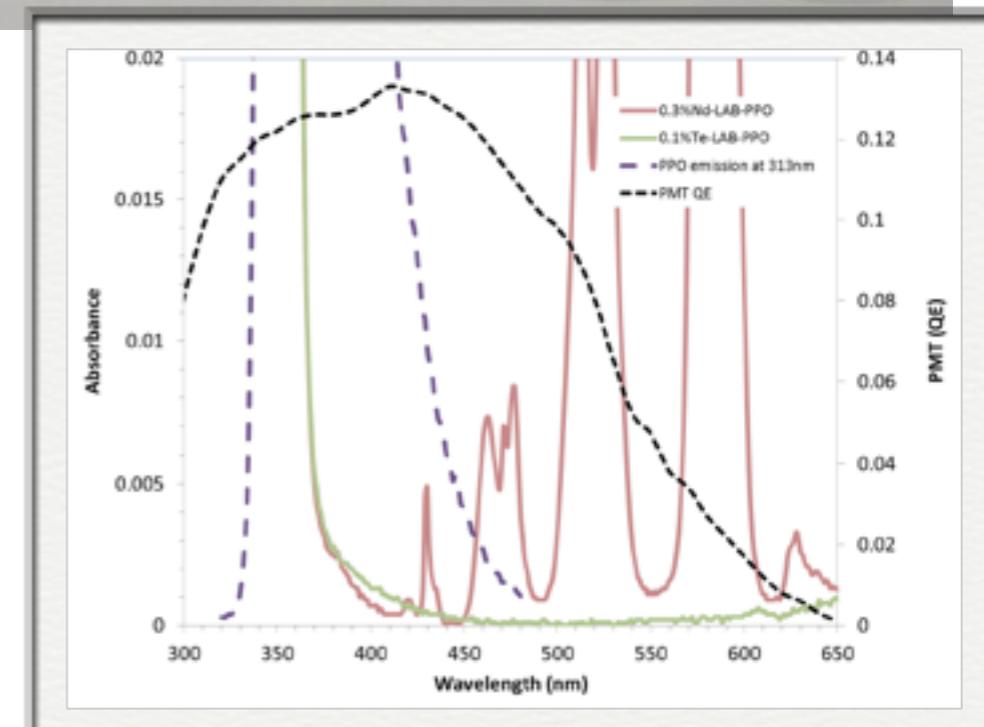
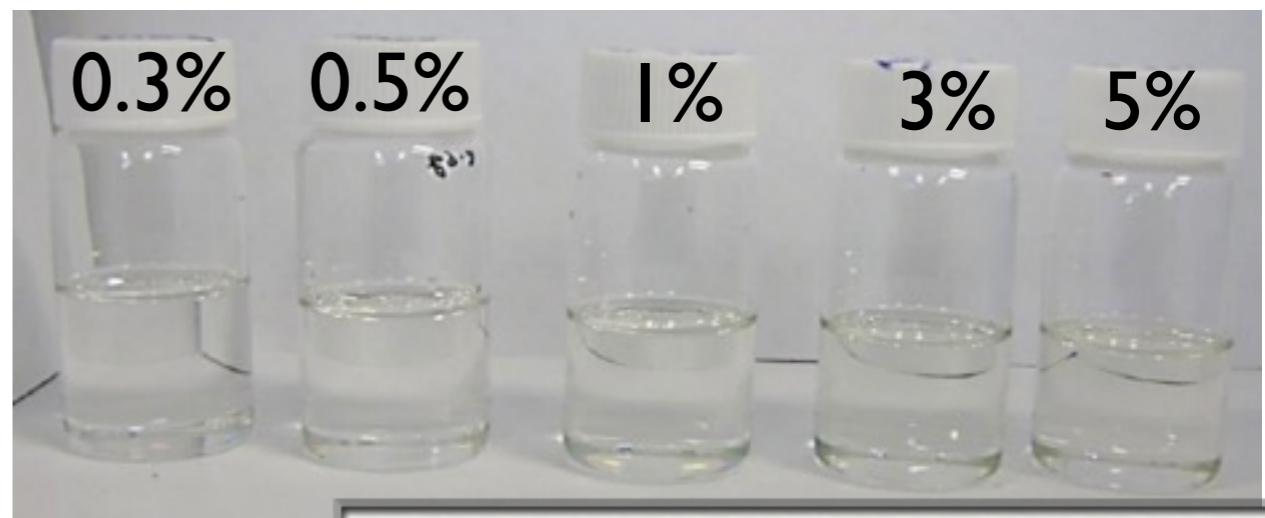
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- Metal-loading R&D:

- *Increase light yield*
- *Reduce correlation loading/optics*

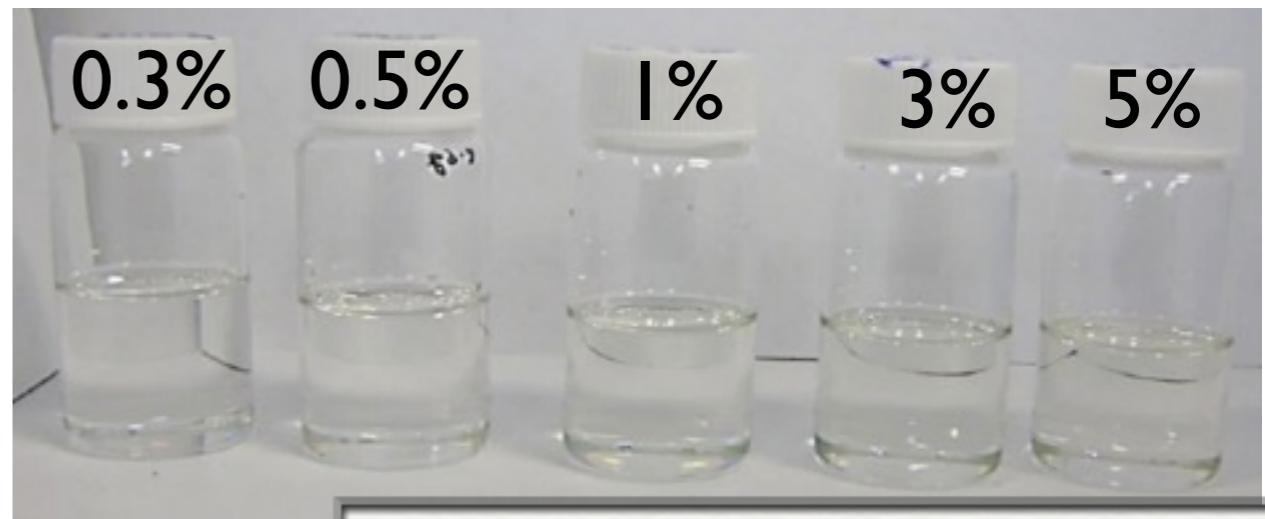


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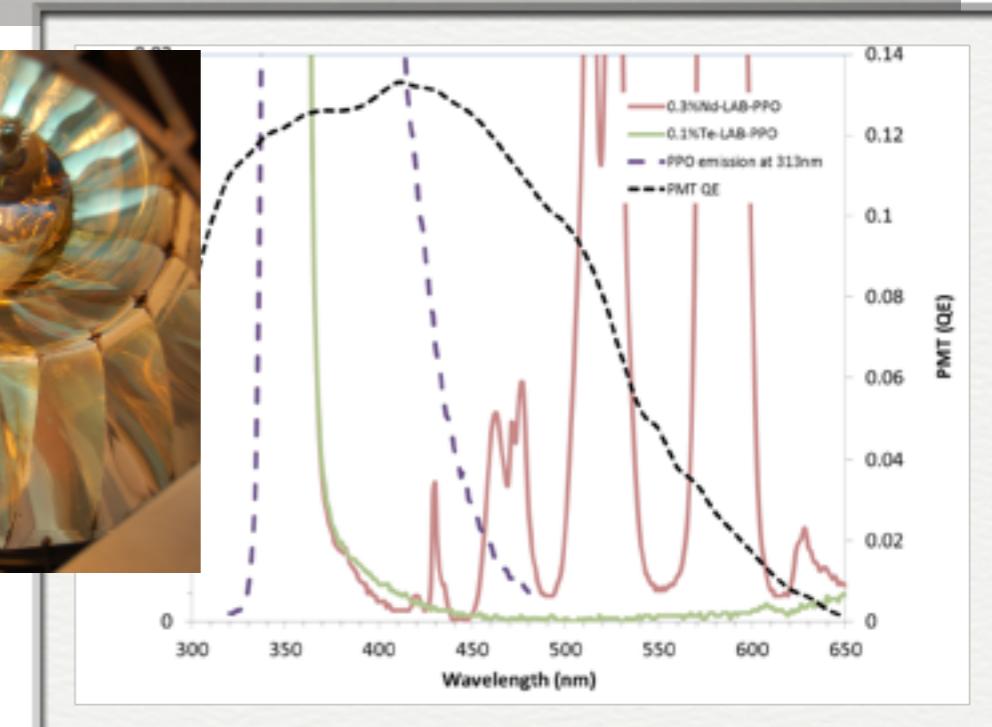
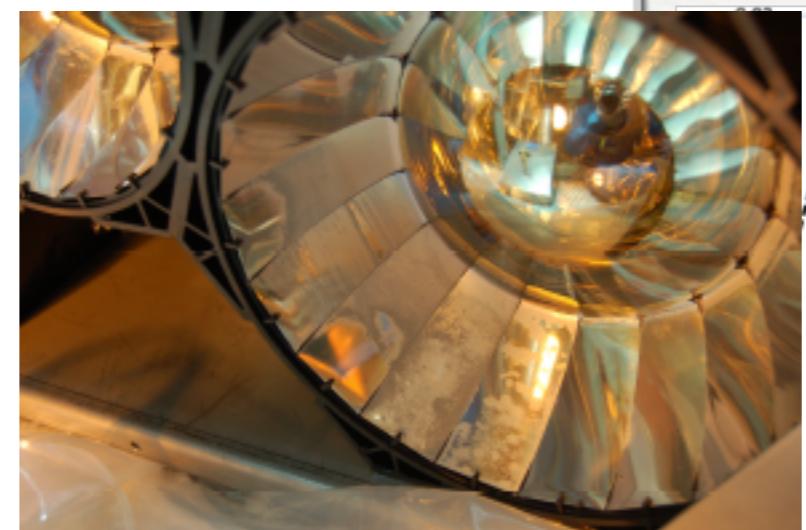
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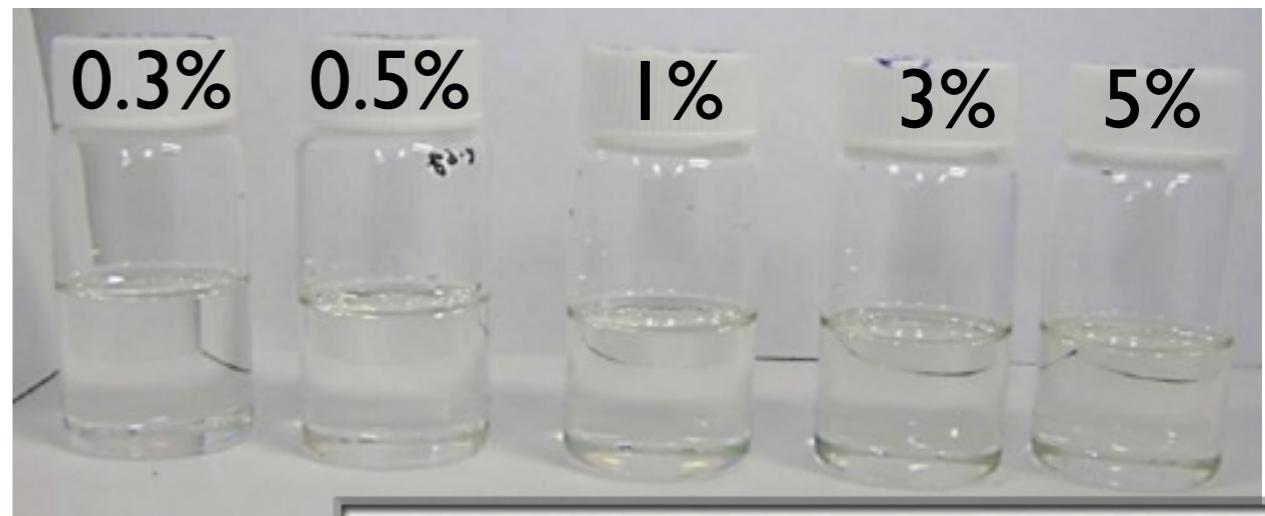


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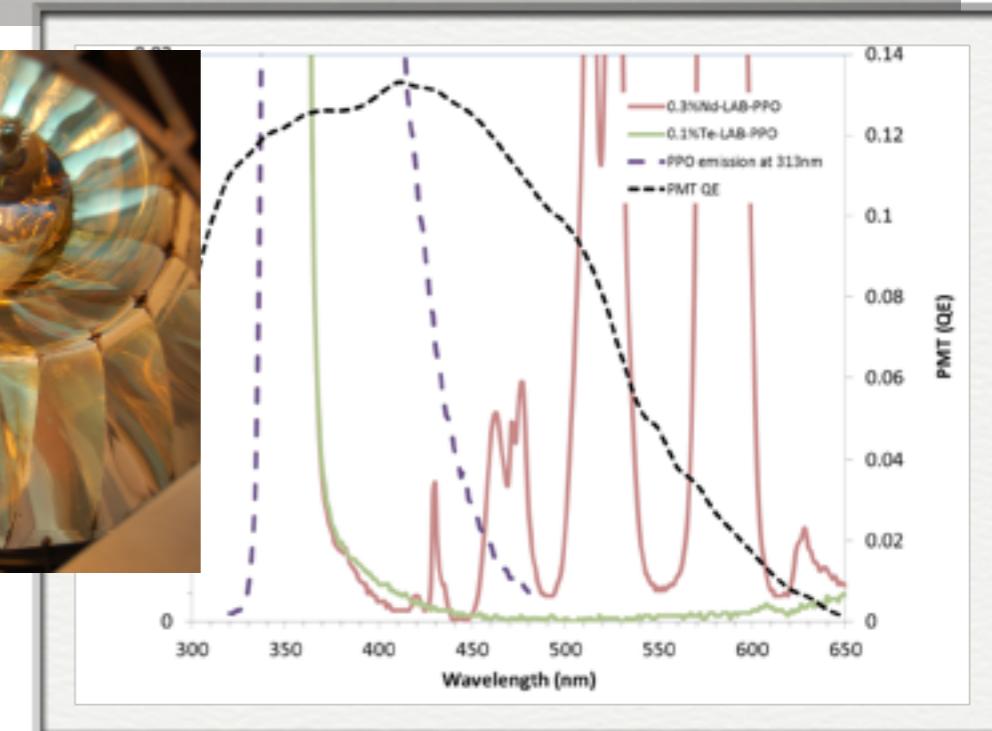
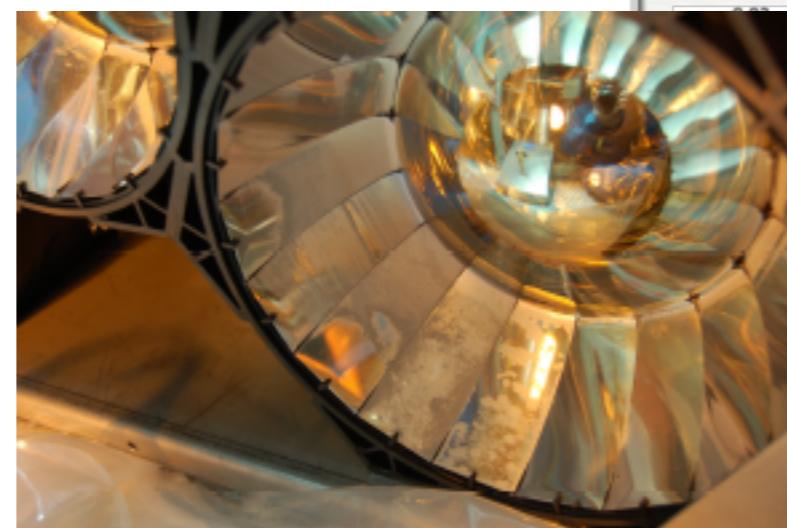
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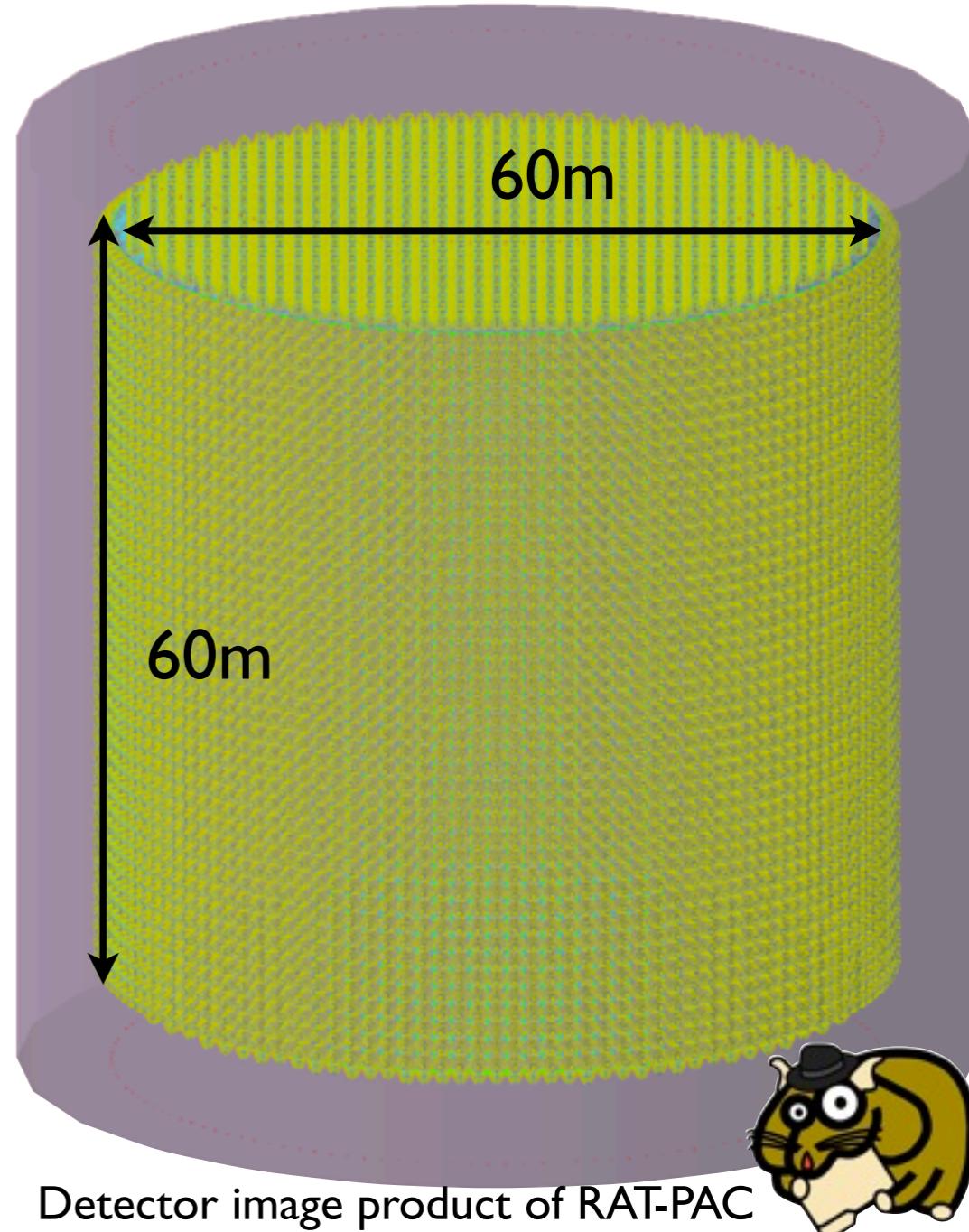
➡ OR: a new, large-scale experiment

THEIA: A realisation of the Advanced Scintillation Detector Concept (ASDC)

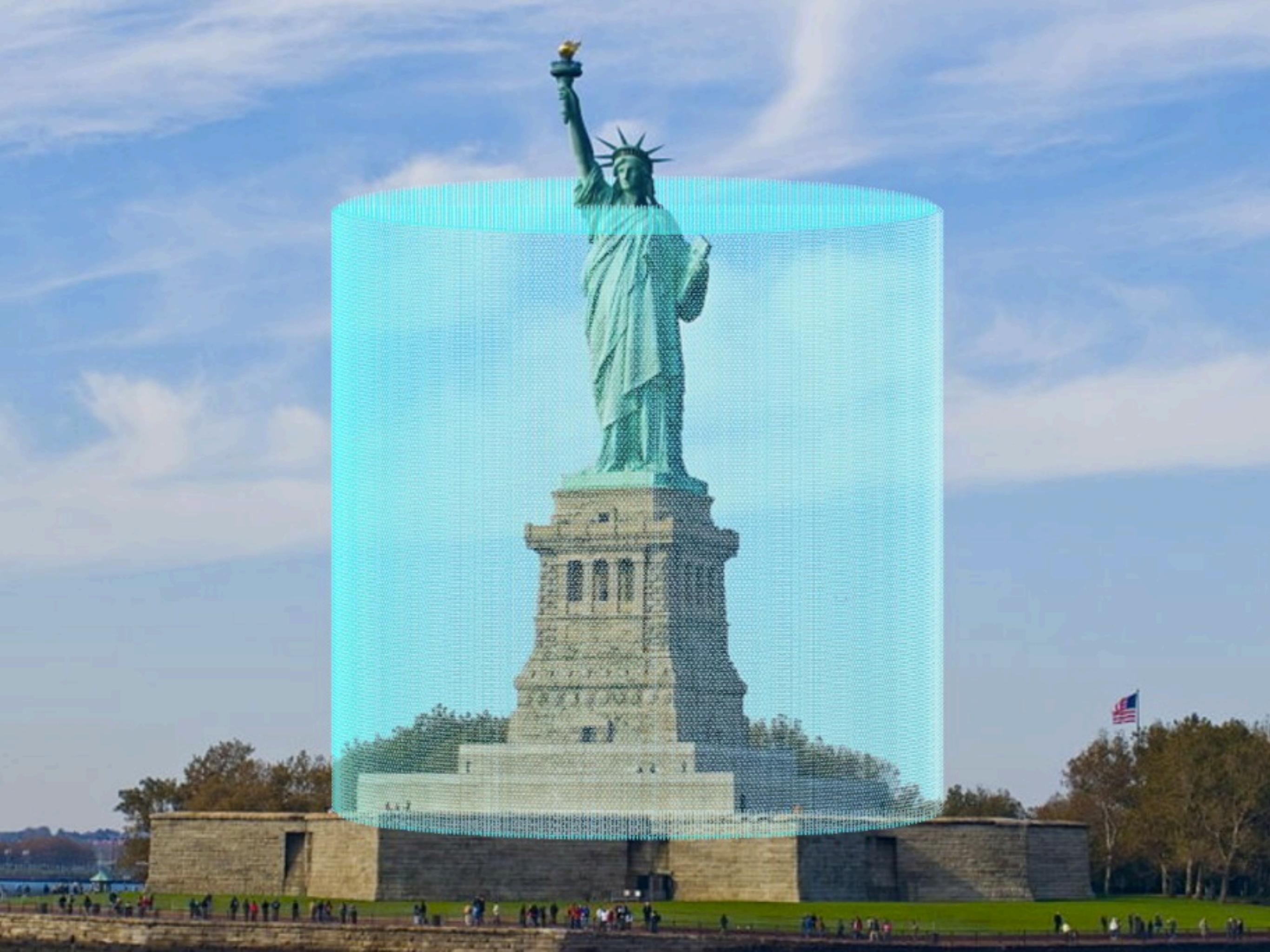
Concept paper - [arXiv:1409.5864](https://arxiv.org/abs/1409.5864)

- 50-100 kton WbLS target (*talk by M.Yeh*)
- High coverage with ultra-fast, high efficiency photon sensors (*talk by M.Wetstein*)
- 4800 m.w.e. underground (Homestake)
- Comprehensive low-energy program: solar neutrinos, supernova, DSNB, proton decay, geo-neutrinos, DBD (*talks by M. Smy, B. Svoboda, G. D. Orebi Gann*)
- In the LBNF beam: long-baseline program complementary to proposed LAr detector (*talk by B. Svoboda*)

➡ **Broad physics program!**







Having our



- Simple mixture of oil and water (!)
⇒ **water-based liquid scintillator (WbLS)** -- Minfang Yeh, BNL

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....

& eating it too!

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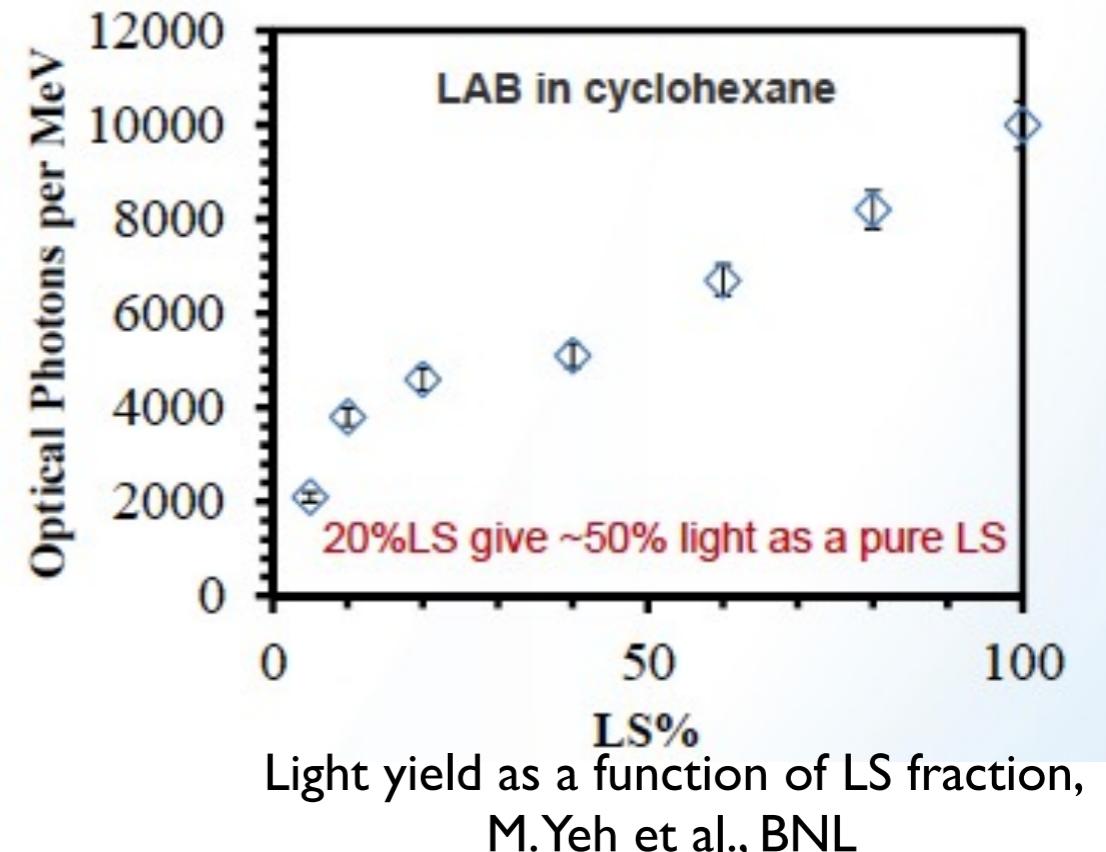
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I. High light yield of organic scintillator

- a) *Low energy threshold*
- b) *Good energy resolution*



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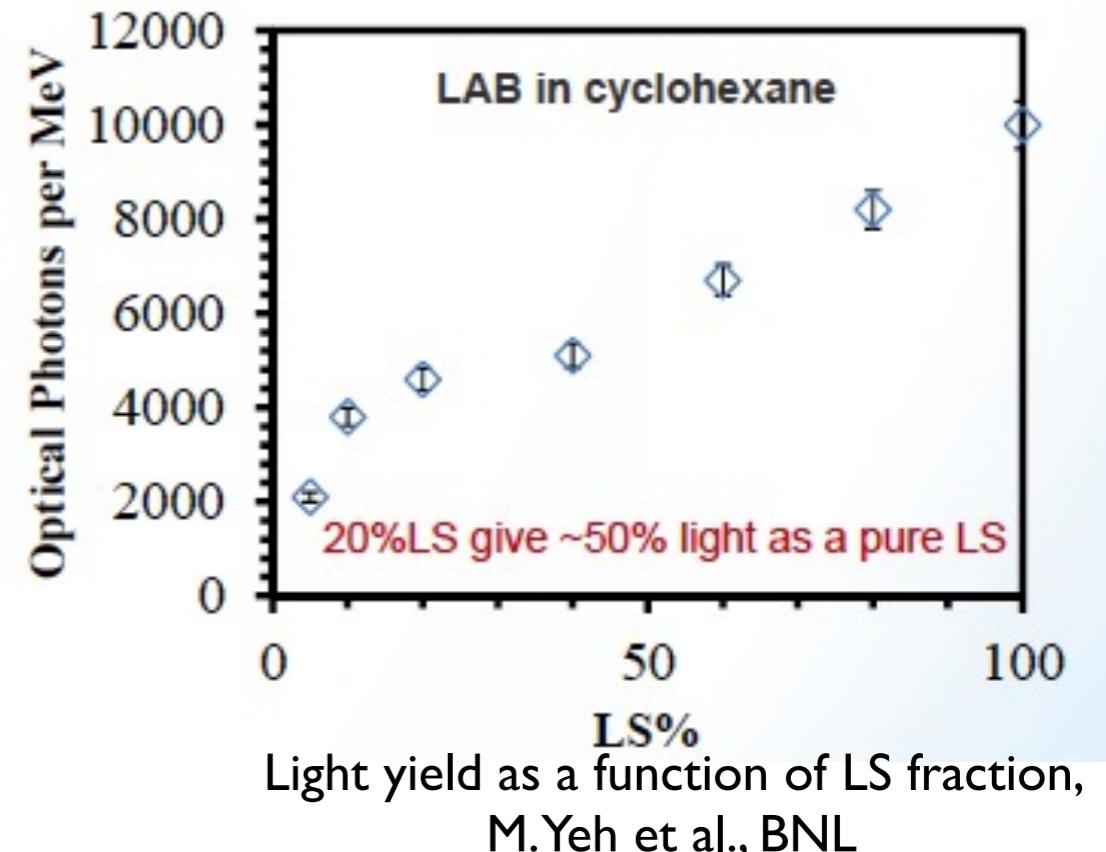
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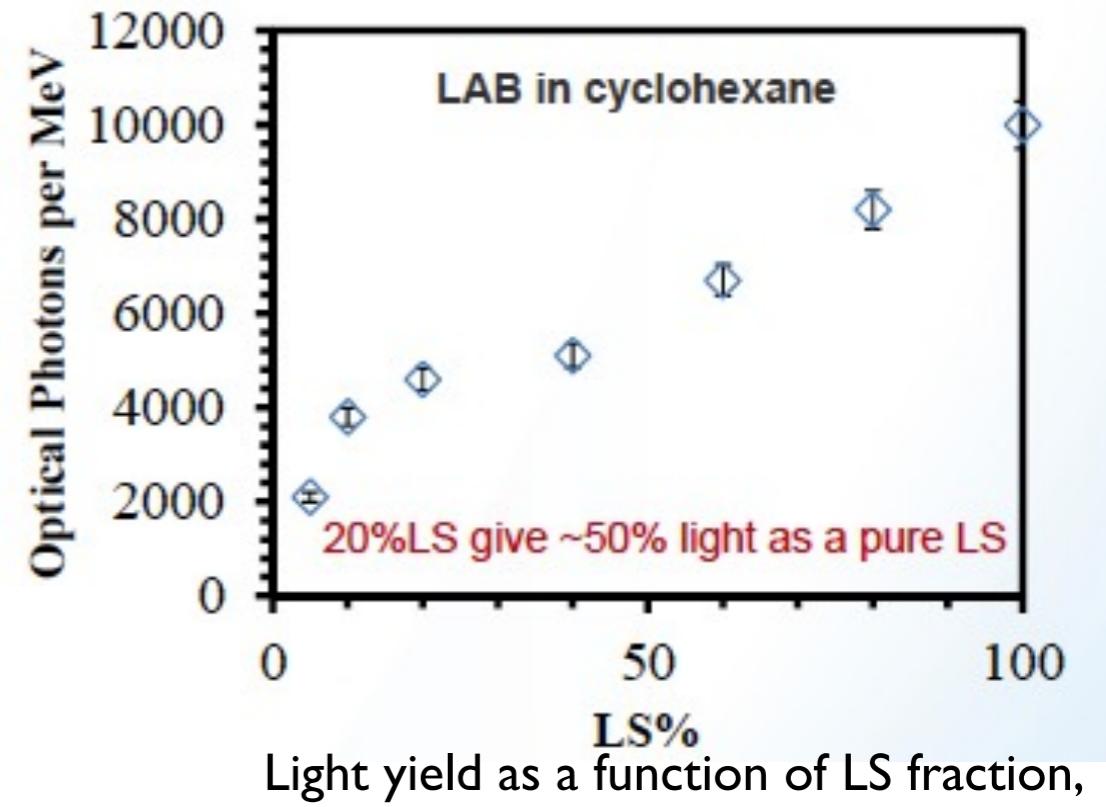
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- improve particle ID, signal identification, bkg separation
- Cher / scint separation



Light yield as a function of LS fraction,
M.Yeh et al., BNL

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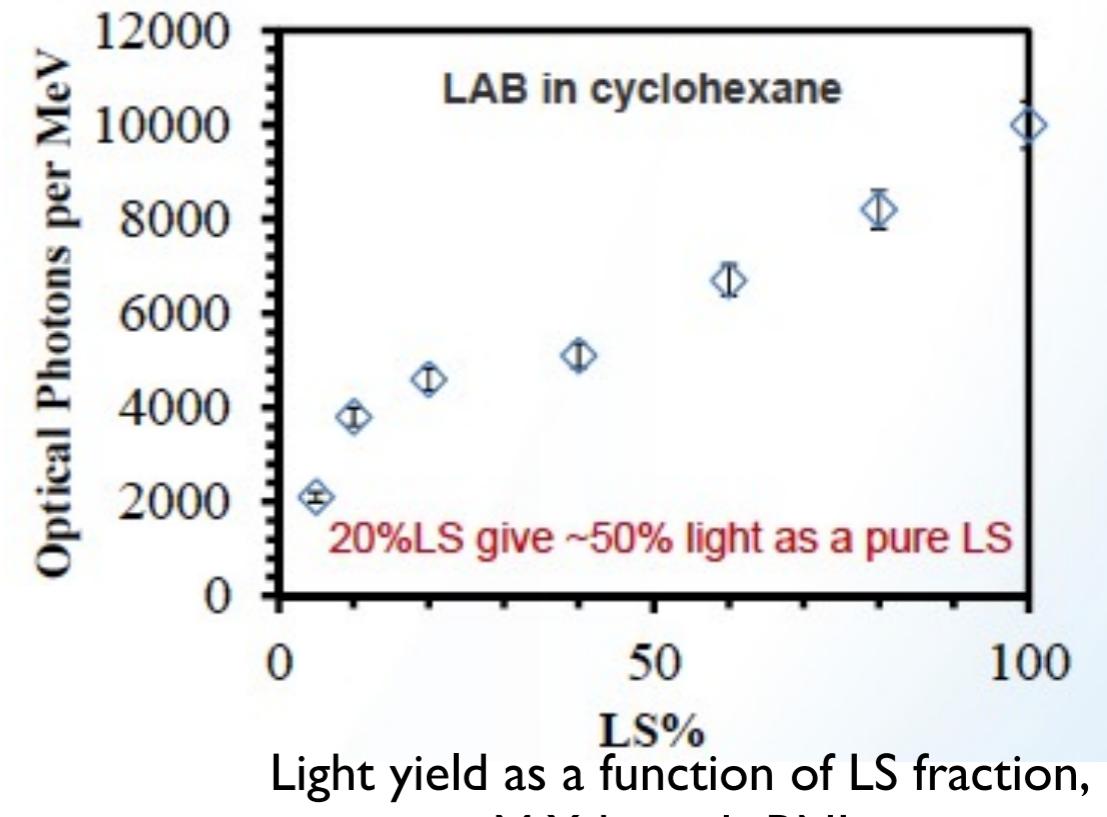
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4. Loading of metallic ions

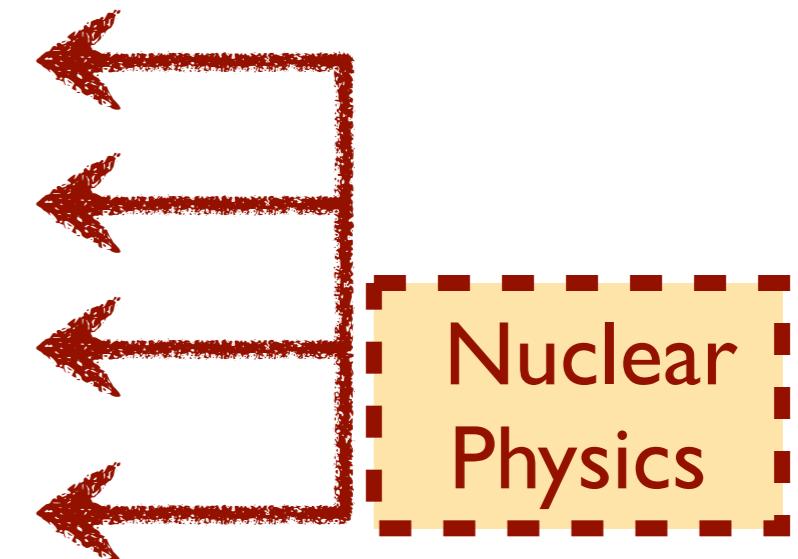
- broad physics applications

Physics Program

1. Long-baseline physics (mass hierarchy, CP violation)
2. Neutrinoless double beta decay
3. Solar neutrinos (solar metallicity, luminosity)
4. Supernova burst neutrinos & DSNB
5. Geo-neutrinos
6. Nucleon decay
7. Source-based sterile searches

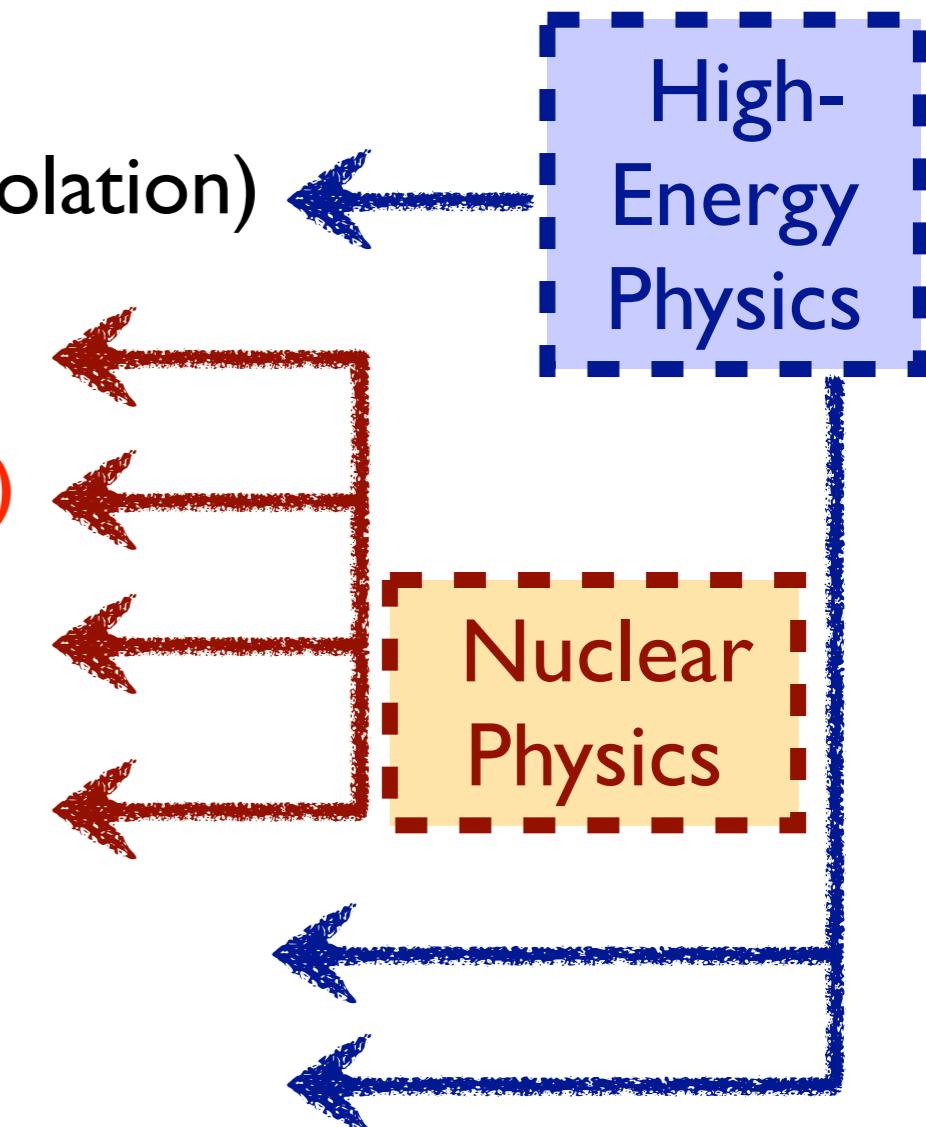
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High-
Energy
Physics

Nuclear
Physics

Physics over
5 orders of
magnitude

THEIA “Interest Group”



Brookhaven National Laboratory
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of Chicago
Columbia University
University of Hawaii at Manoa
Hawaii Pacific University
Iowa State University
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory



RWTH Aachen University
TUM, Physik-Department
University of Hamburg
Johannes Gutenberg-University Mainz



Brunel University

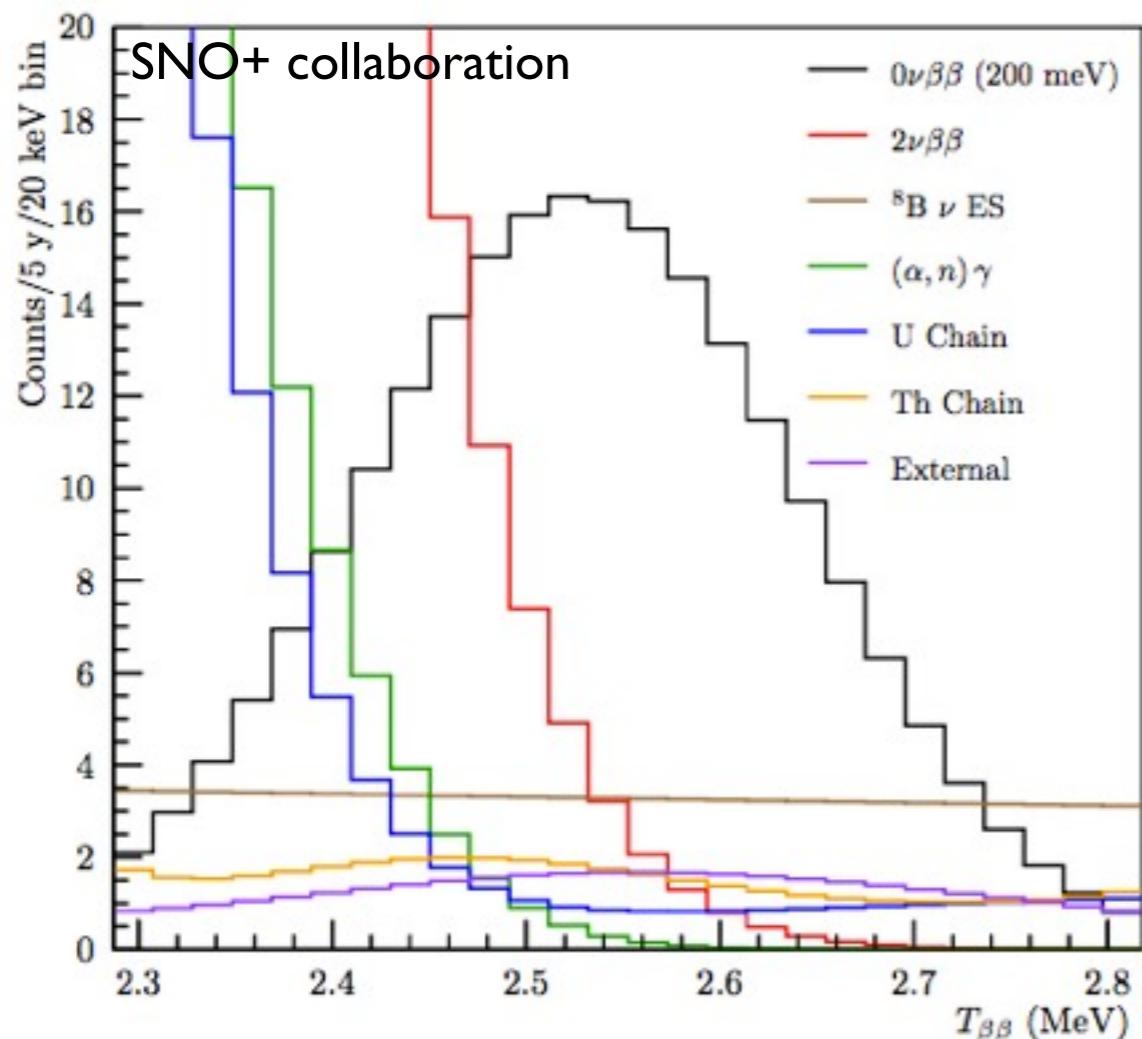
Los Alamos National Laboratory
University of Maryland
MIT
University of Pennsylvania

Princeton University
Sandia National Laboratories
Virginia Polytechnic Inst. & State University
University of Washington

New participation welcome
contact G. D. Orebí Gann, B. Svoboda, E. Blucher, J. R. Klein

Background Reduction

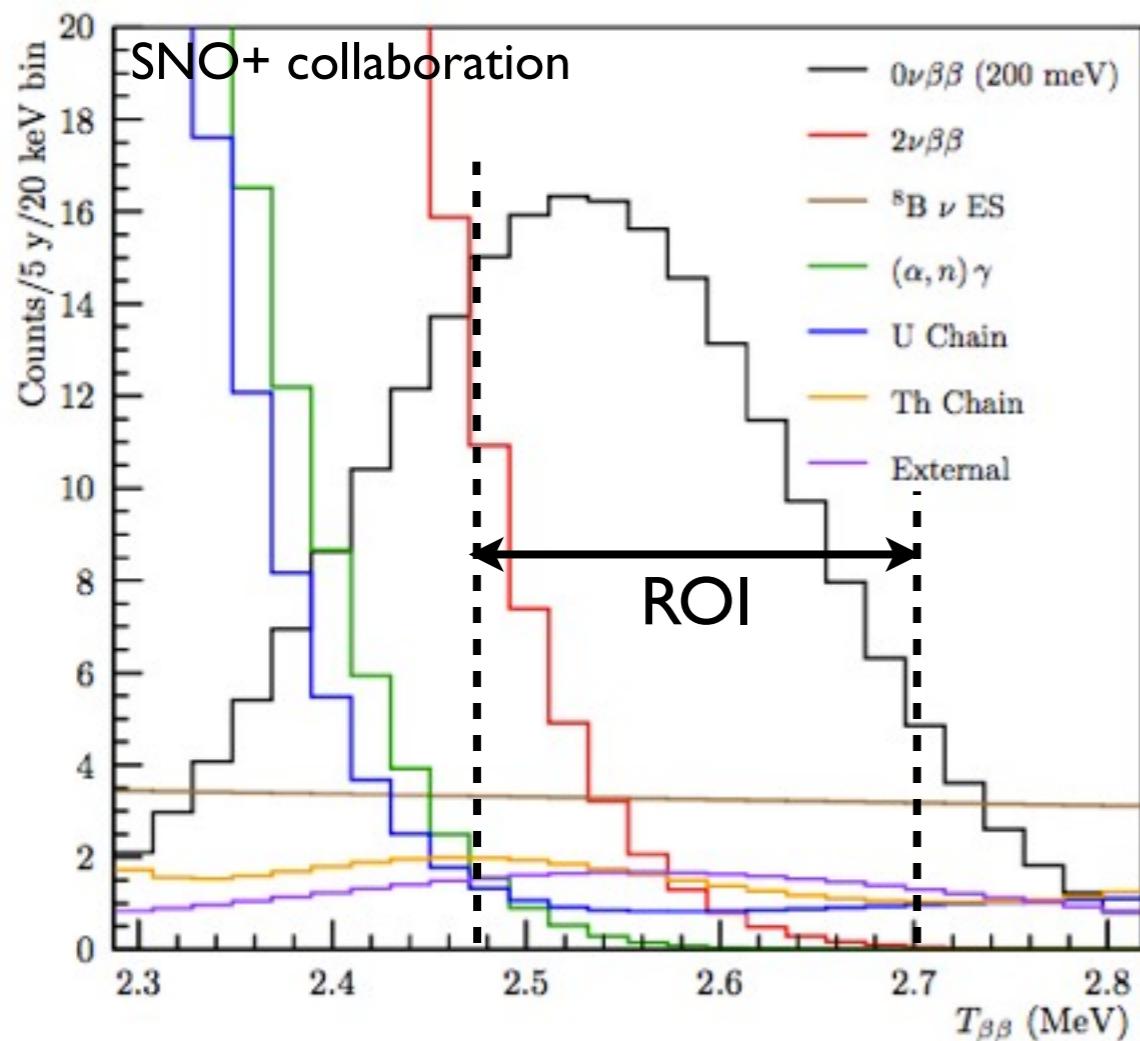
Projected spectrum in SNO+: 5 years, 0.3% ^{nat}Te



Asymmetric ROI (-0.5 - 1.5 σ):
2.1 $2\nu\beta\beta$ events / yr
7.3 8B solar ν events / yr

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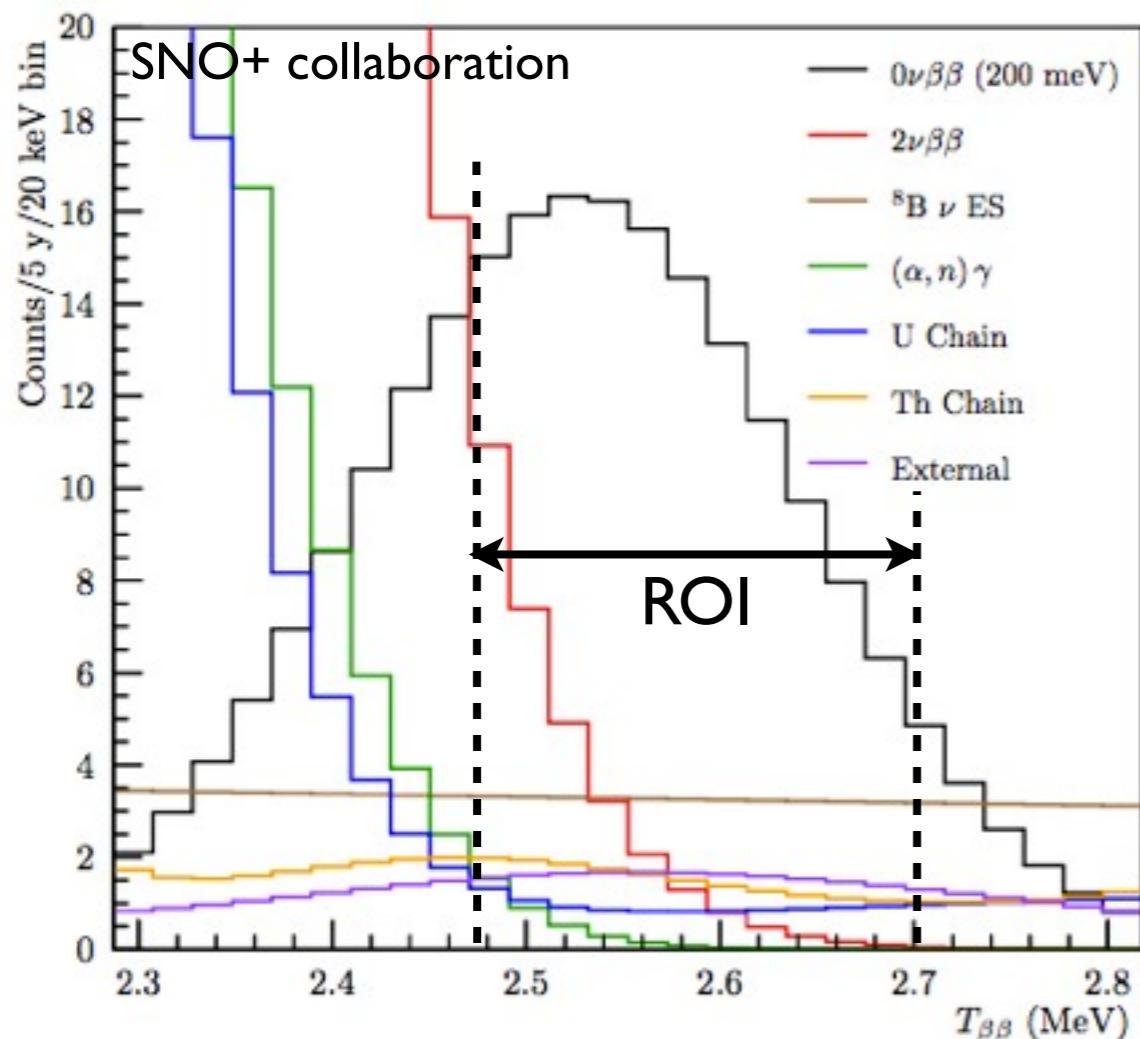
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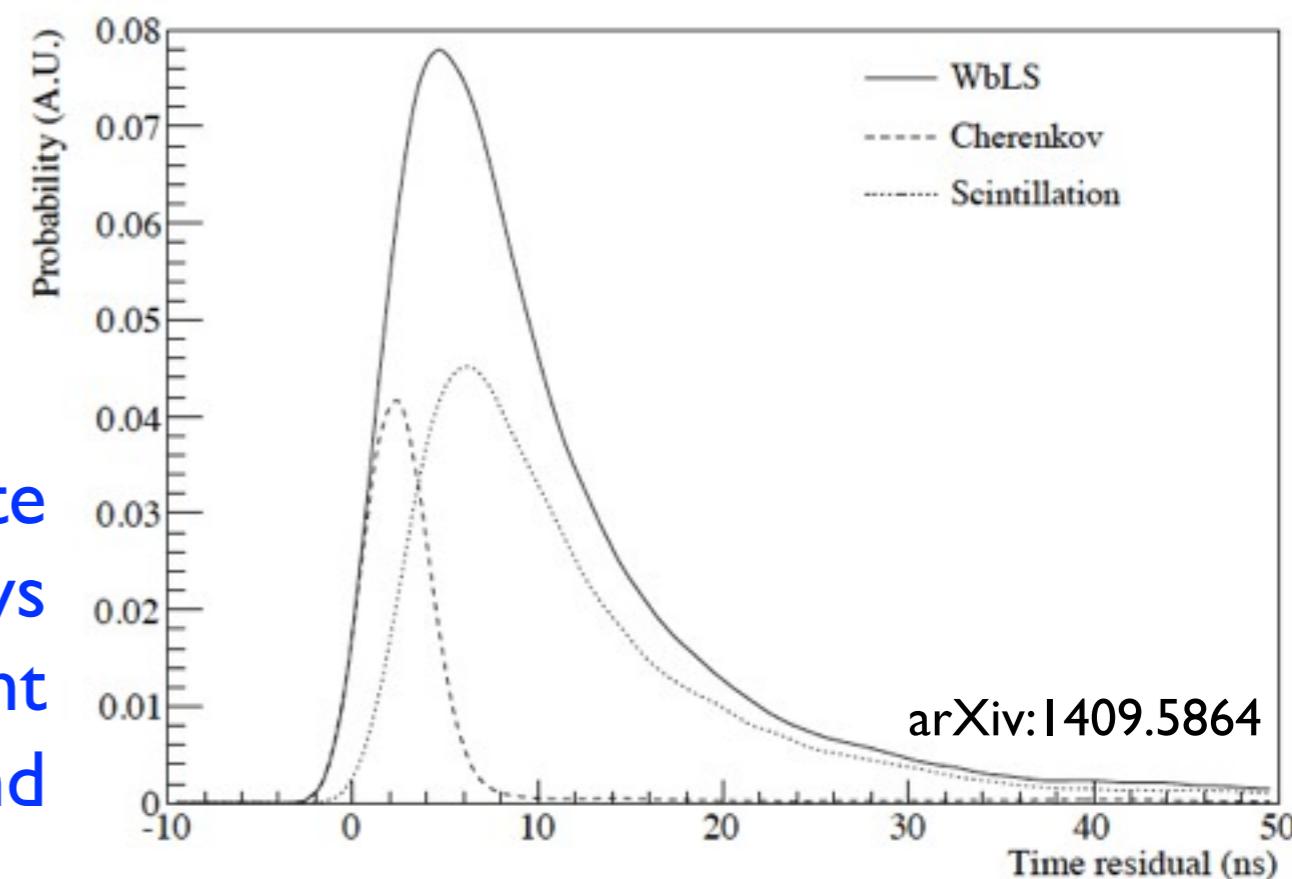
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Use of precision timing to separate
Cher / scint components allows
directional cut to reject dominant
 8B solar ν background

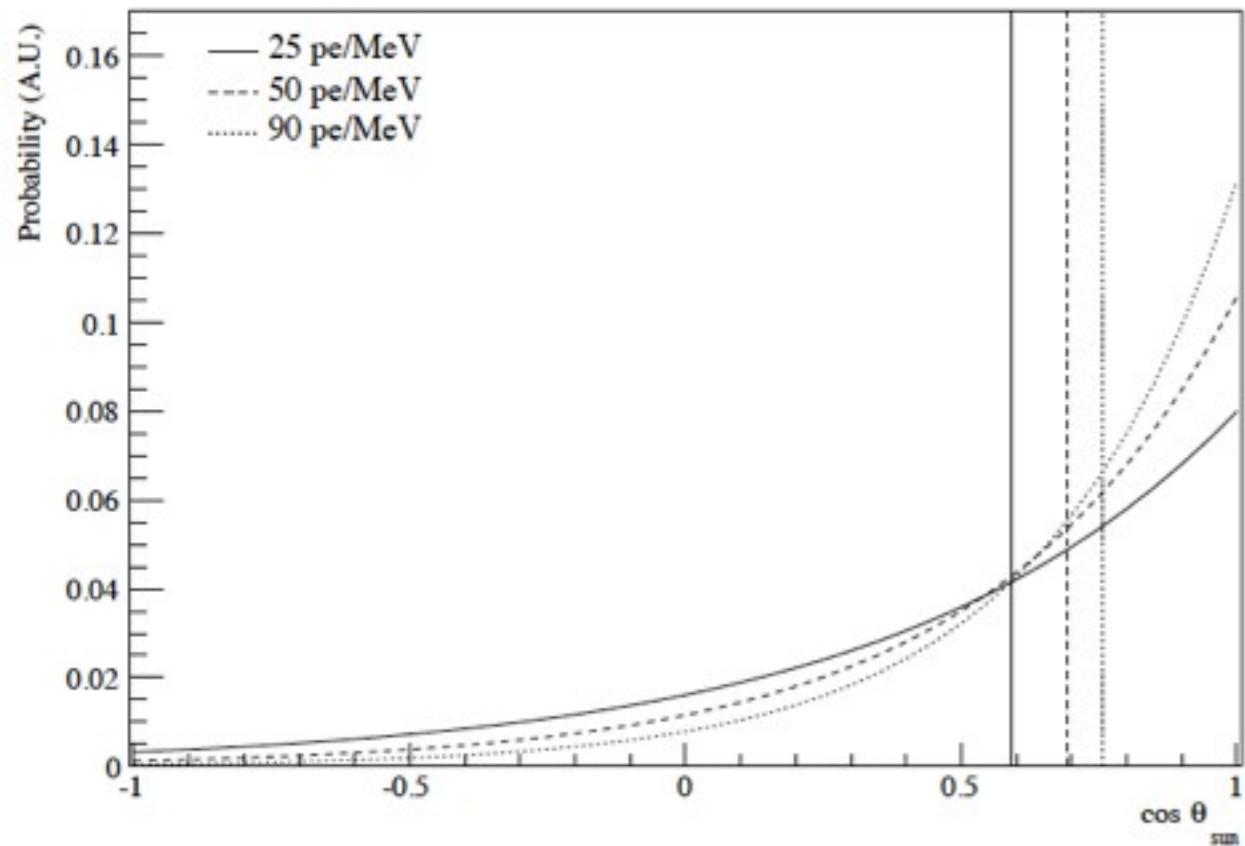


arXiv:1409.5864

Time residual (ns)

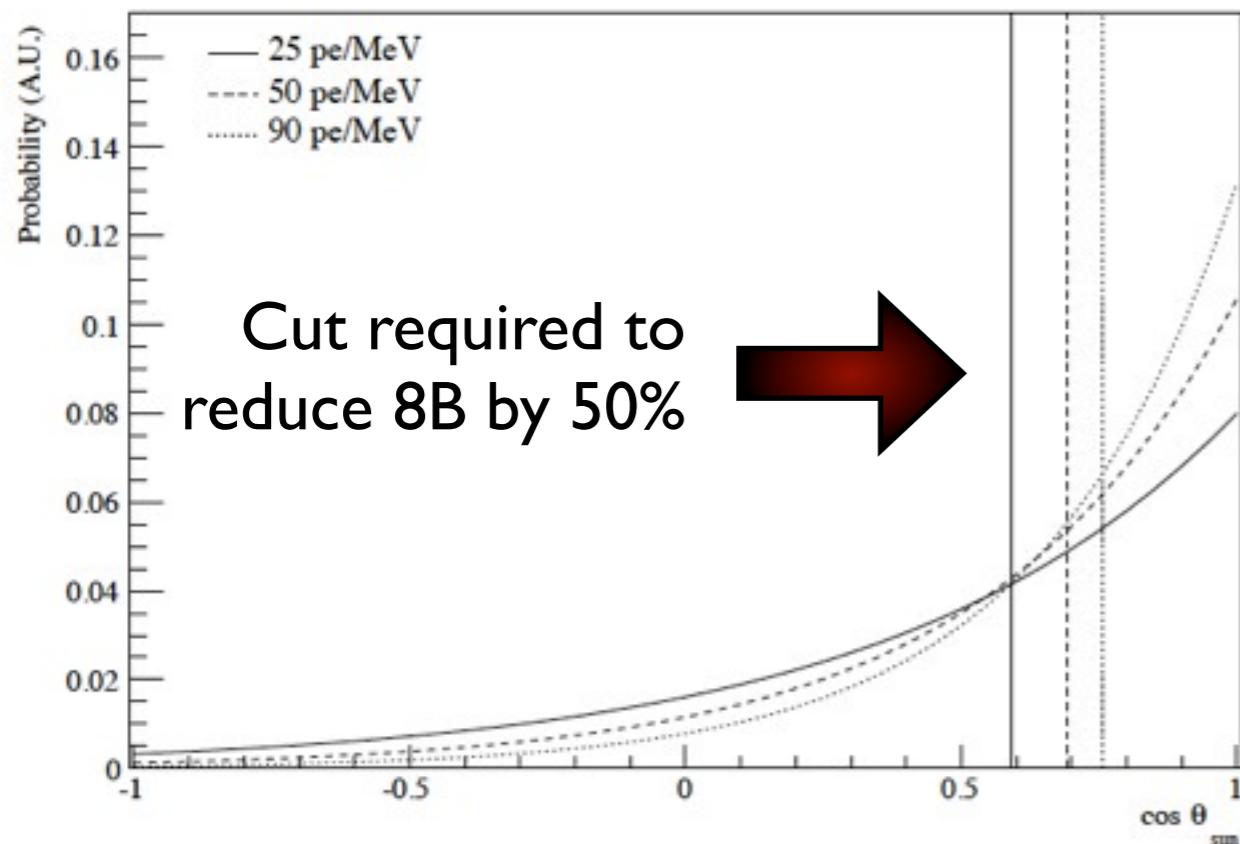
THEIA Sensitivity

Directional resolution for different Cherenkov light yields



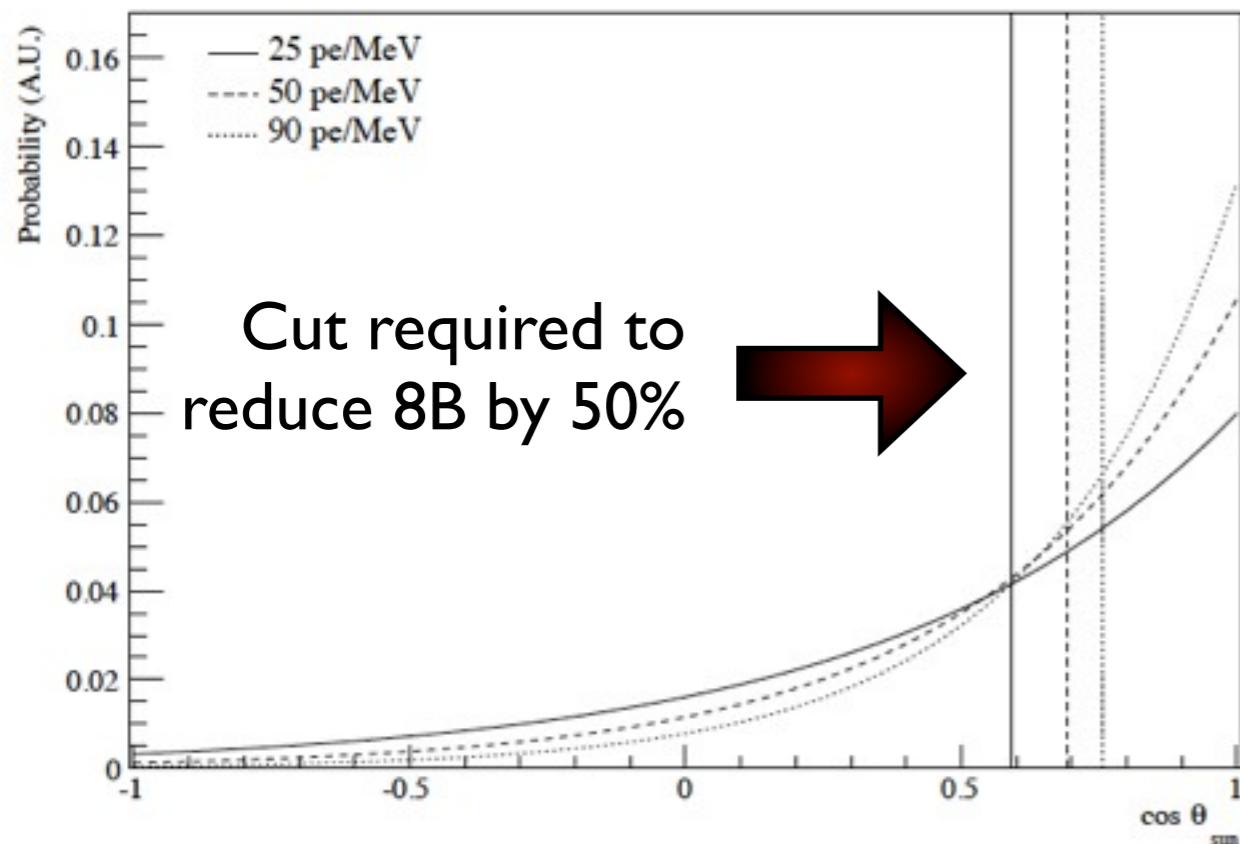
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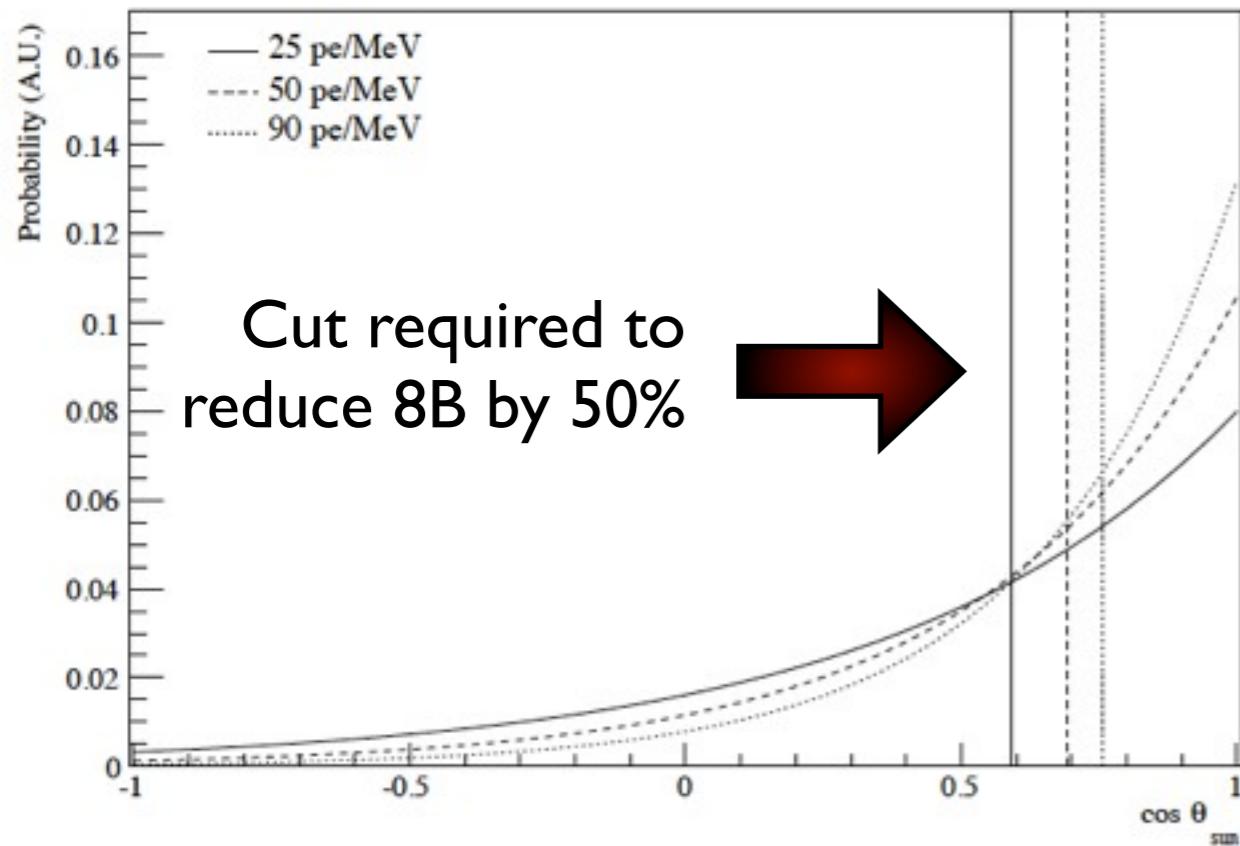
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50kt detector
50% reduction of ${}^8\text{B}$
Particle ID / coincidence tags for int r/a
 $R_{\text{fit}} > 5.5\text{m}$ from PMTs (30kt fid)

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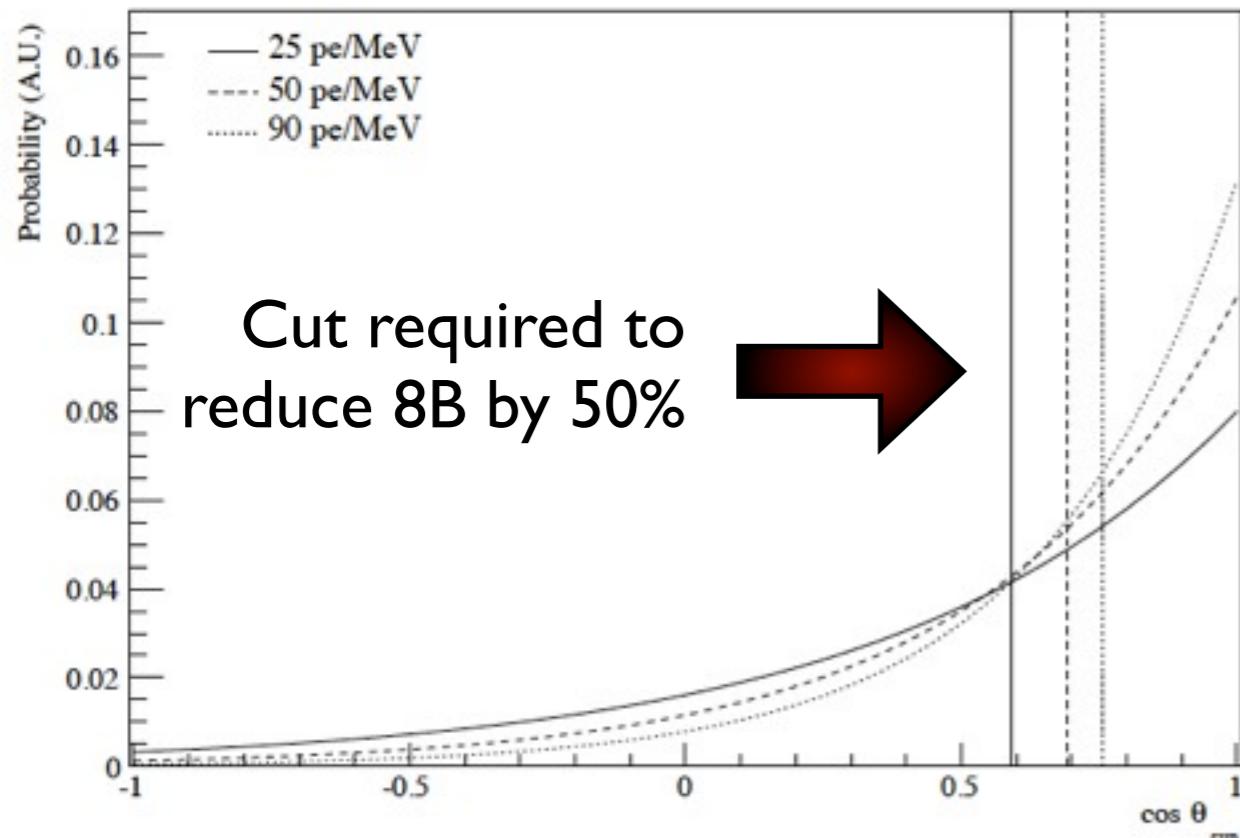
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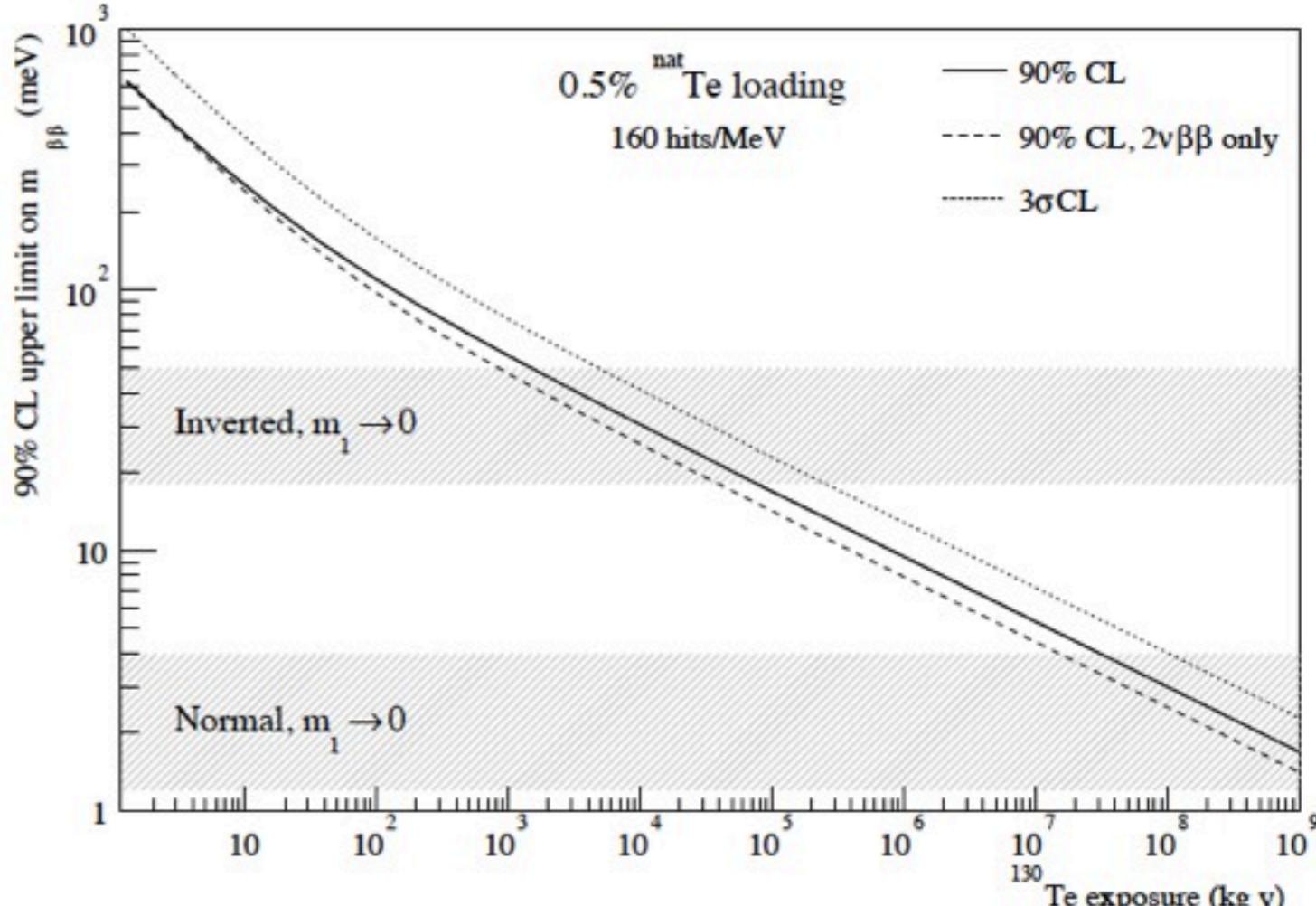
0.5% loading (${}^{\text{nat}}\text{Te}$) in 50kt $\Rightarrow 50\text{t} {}^{130}\text{Te}$

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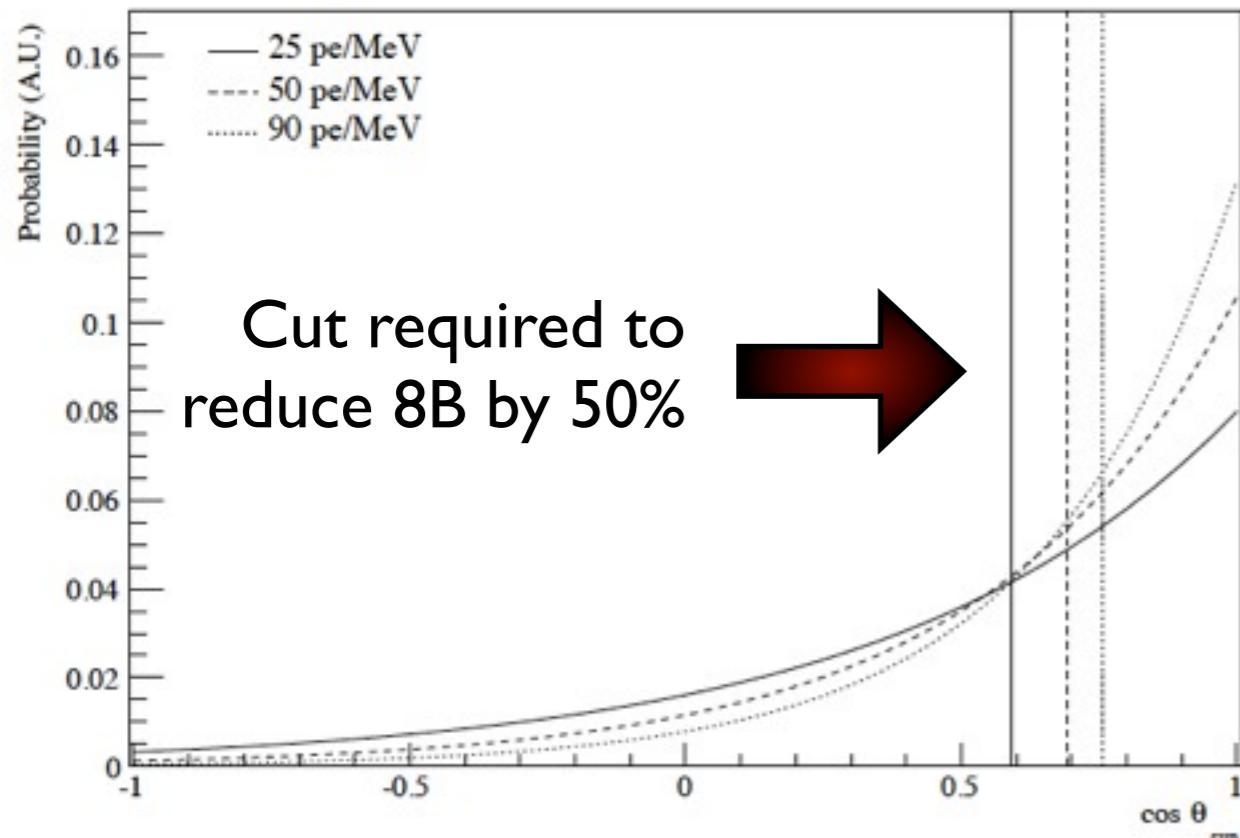


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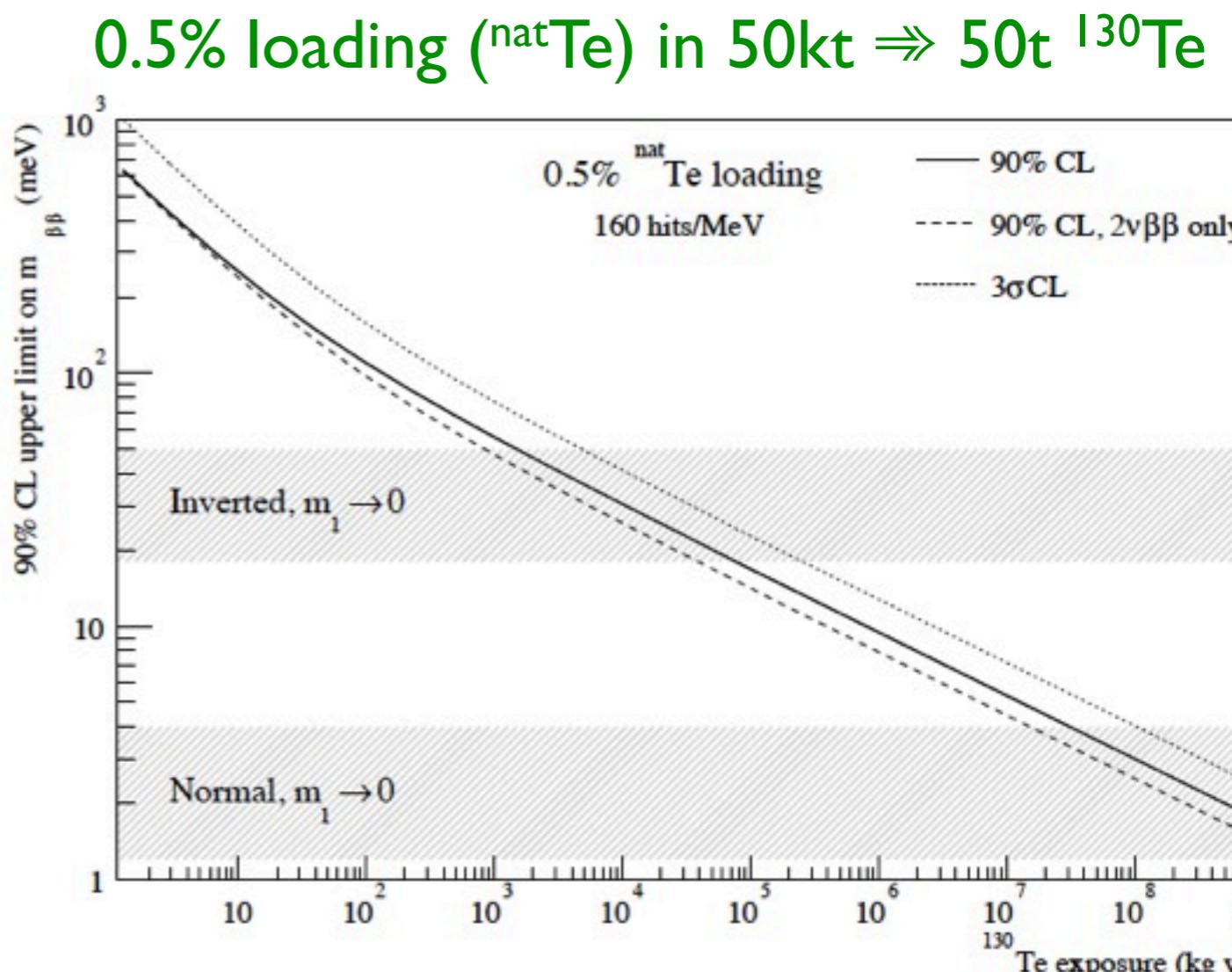
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Cut required to
reduce 8B by 50%

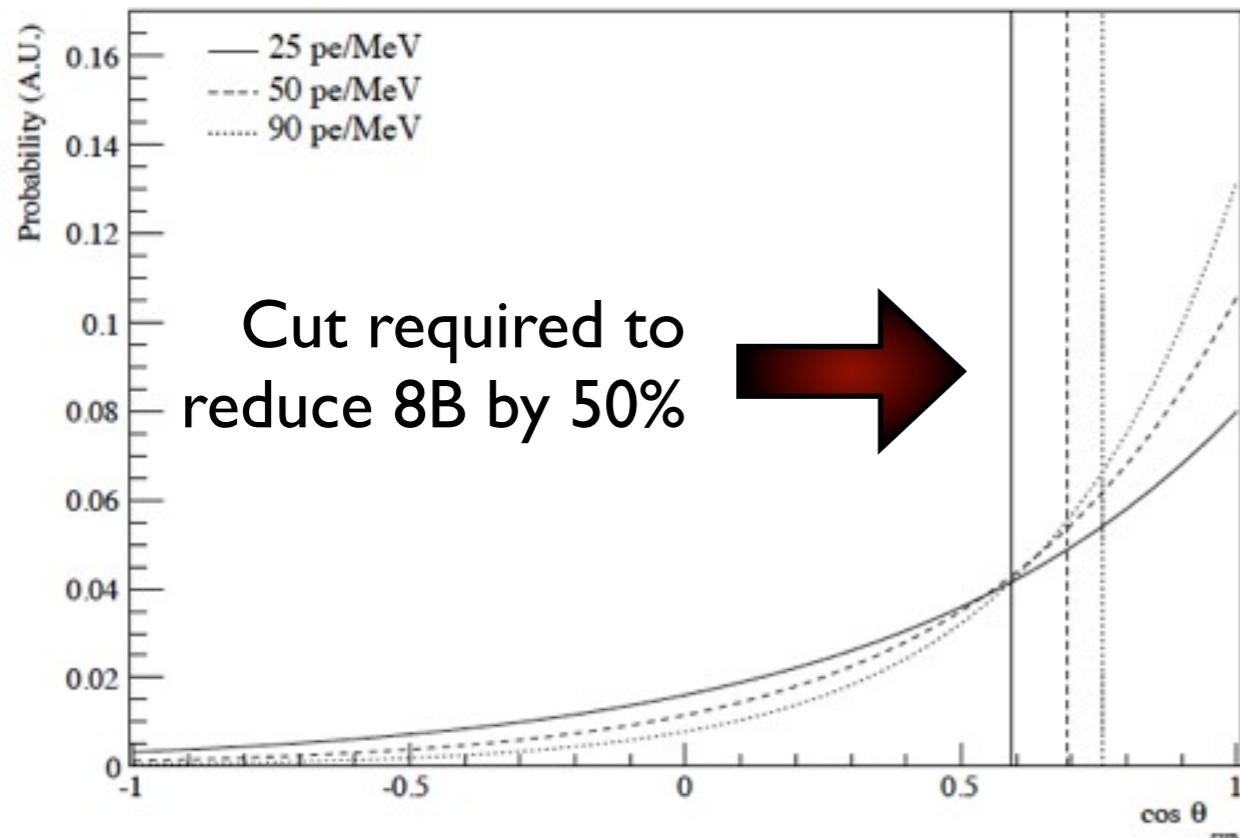
⇒ 3 σ discovery for
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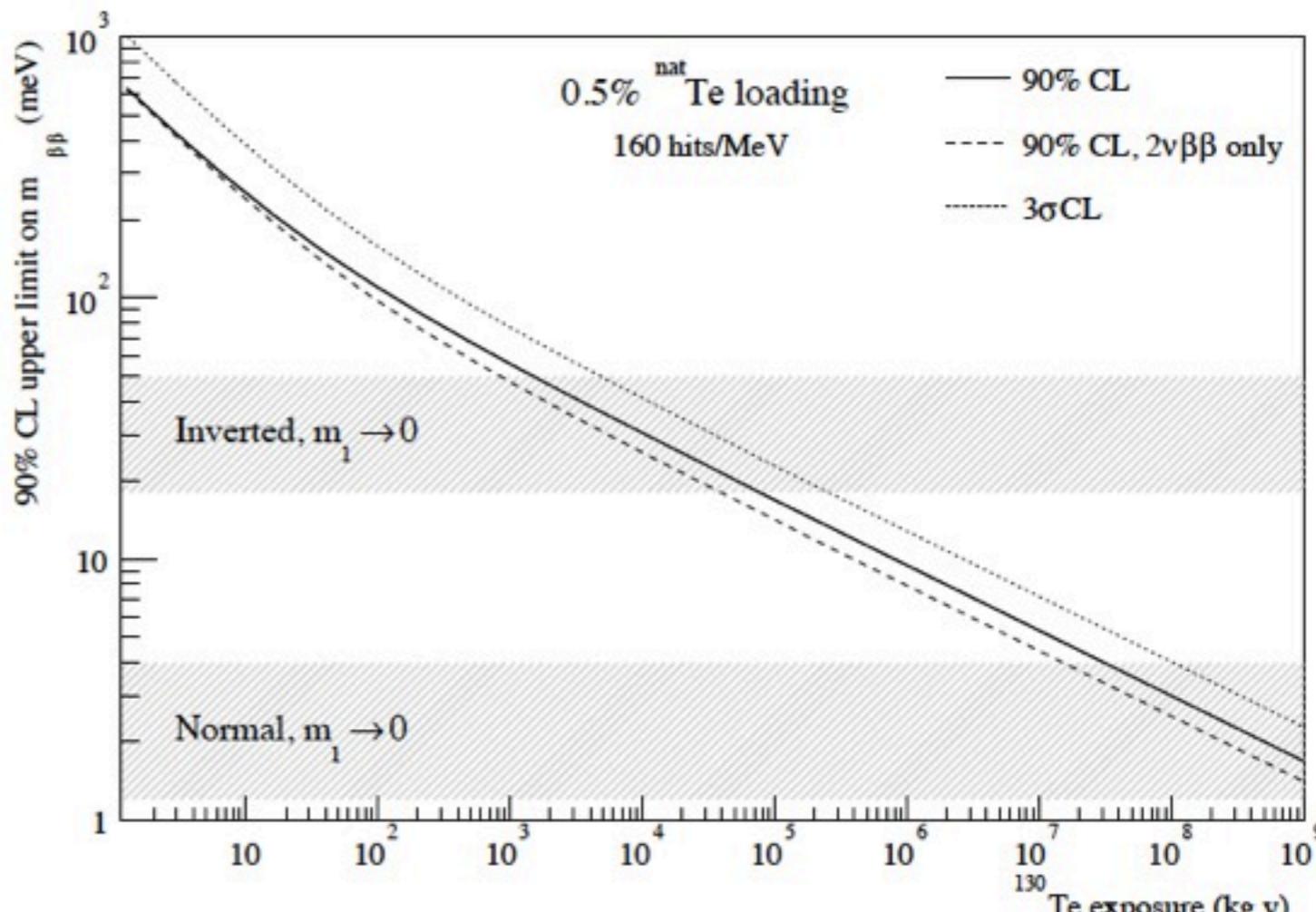
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Future sensitivity into NH region...

Required R&D

Required R&D

I. Sufficient overall light yield

Energy resolution

Required R&D

- I. Sufficient overall light yield *Energy resolution*
- 2. Cherenkov / scintillation separation
 - a) Fast timing
 - b) WbLS cocktail tuning

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- I. Sufficient overall light yield *Energy resolution*
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+ *Directionality*
+ *Particle ID*

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Ring imaging capability
+ *Directionality*
+ *Particle ID*
- 3. Cherenkov light yield *See above*
- 4. Attenuation length *Energy resolution*

Required R&D

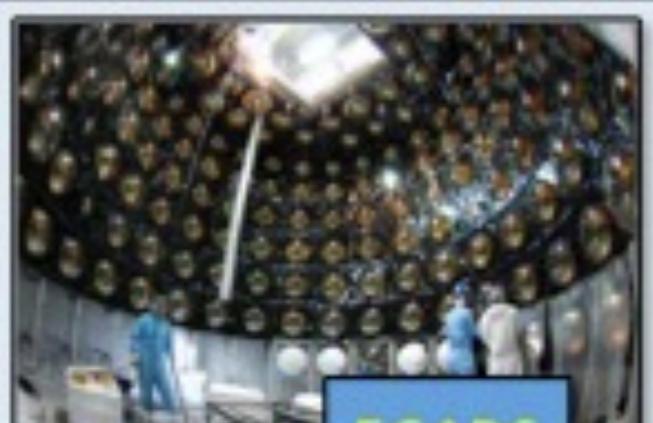
- I. Sufficient overall light yield *Energy resolution*
- 2. Cherenkov / scintillation separation
 - a) Fast timing *Ring imaging capability*
 - b) WbLS cocktail tuning *+Directionality
+ Particle ID*
- 3. Cherenkov light yield *See above*
- 4. Attenuation length *Energy resolution*
- 5. Reconstruction & particle ID *Bkg rejection*

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- 6. Isotope loading *0v $\beta\beta$, solar, n tagging etc*

Planned Demonstrations

Site	Scale	Target	Measurements	Timescale
UChicago	bench top	H ₂ O	fast photodetectors	Exists
CHIPS	10 kton	H ₂ O	electronics, readout, mechanical infrastructure	2019
EGADS	200 ton	H ₂ O+Gd	isotope loading, fast photodetectors	Exists
ANNIE	30 ton			2016
WATCHMAN	1 kton			2019
UCLA/MIT	1 ton	LS	fast photodetectors	2015
Penn	30 L	(Wb)LS	light yield, timing, loading	Exists
SNO+	780 ton			2016
LBNL	bench top	WbLS	light yield, timing, cocktail optimization, loading, attenuation, reconstruction	Early 2015
BNL	1 ton			Summer 2015
WATCHMAN-II	1 kton			2020



EGADS



BNL I-t



SNO+

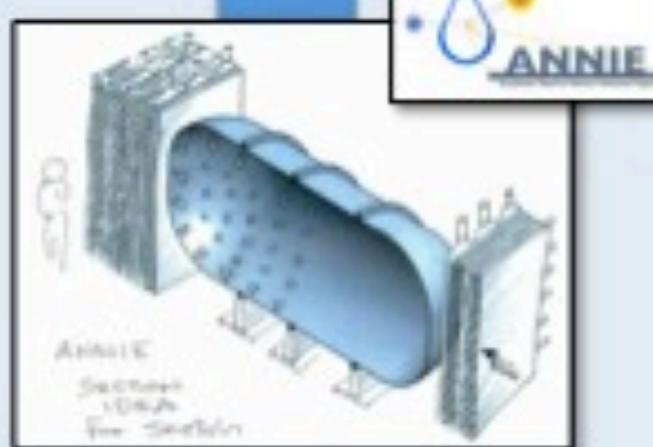
Gd loading and purification

Water-based Liquid Scintillator

Te loading

neutron yield physics
LAPPD fast timing

WbLS, Gd, LAPPD,
HQE PMT full
integration
prototype



ANNIE

WATCHMAN

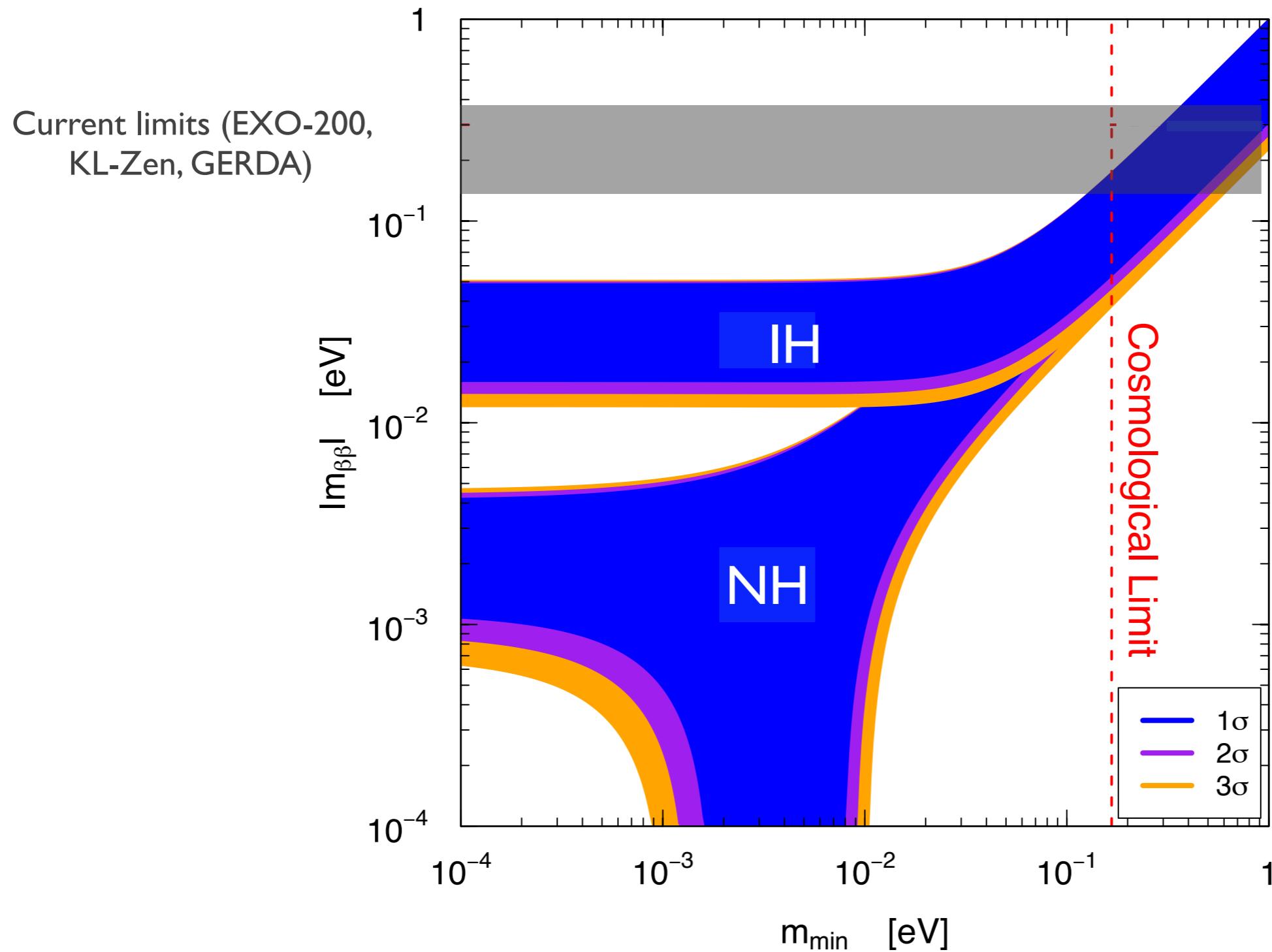


THEIA

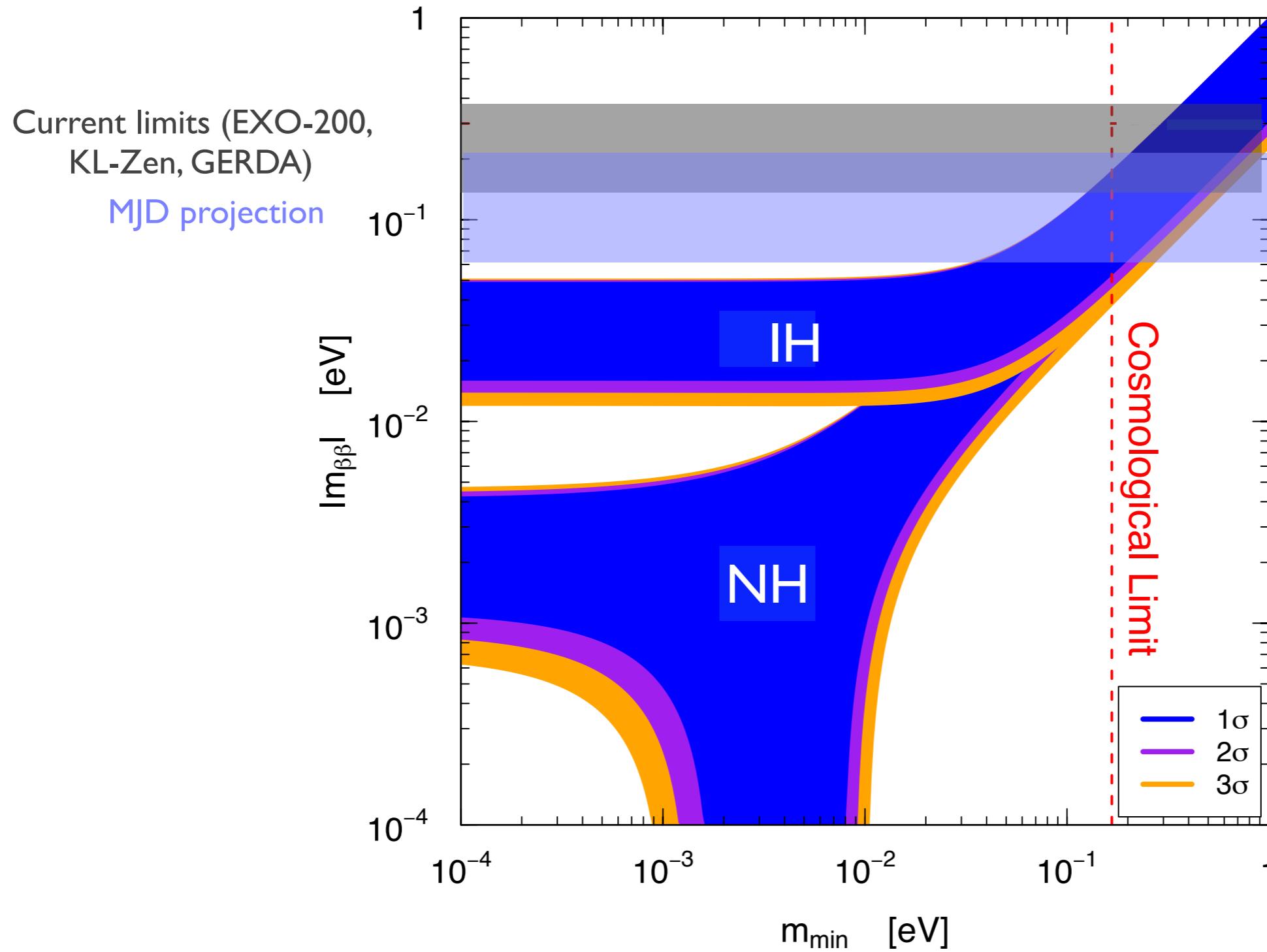


60m

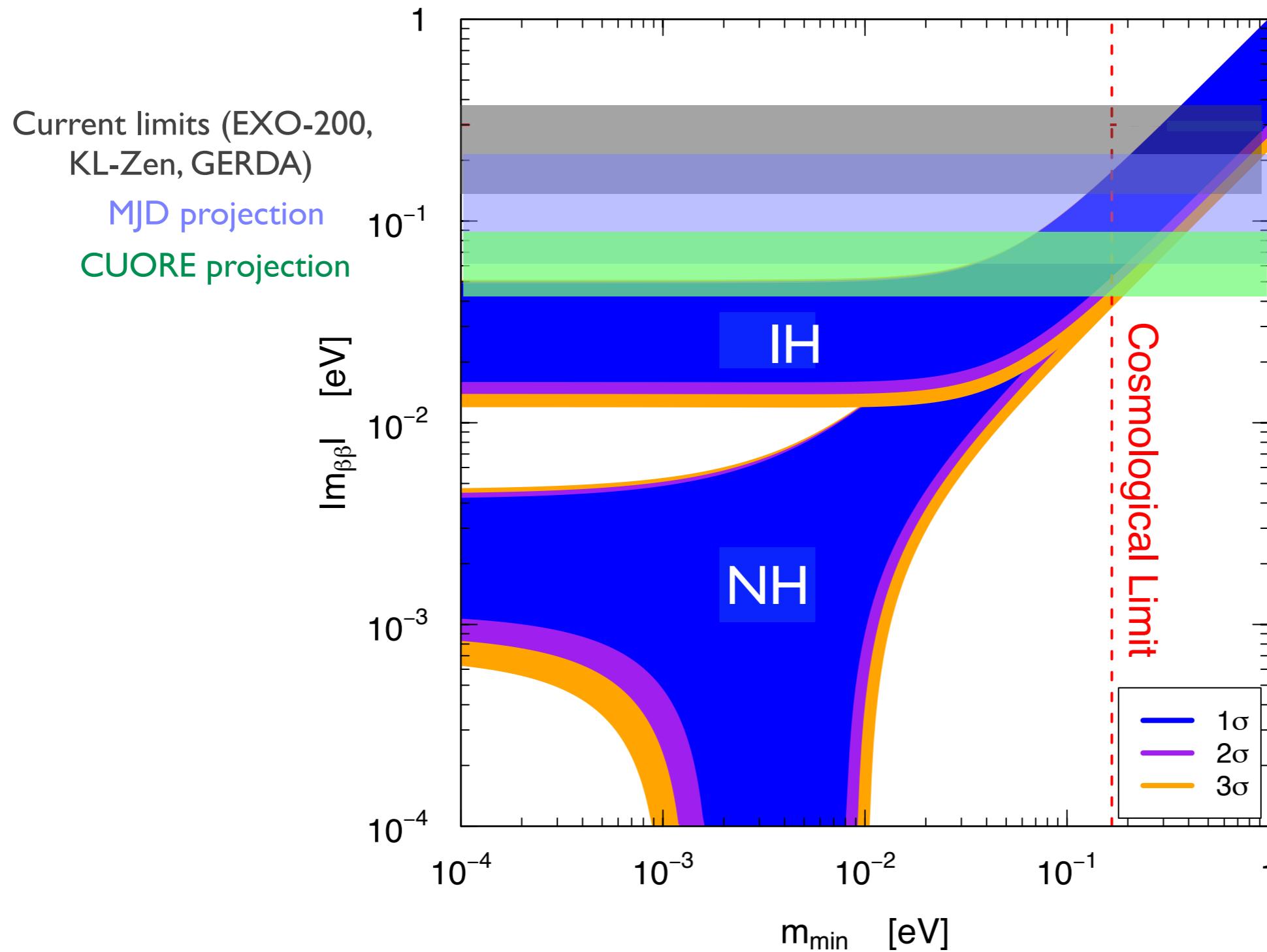
Future Plans: Probing the MH?



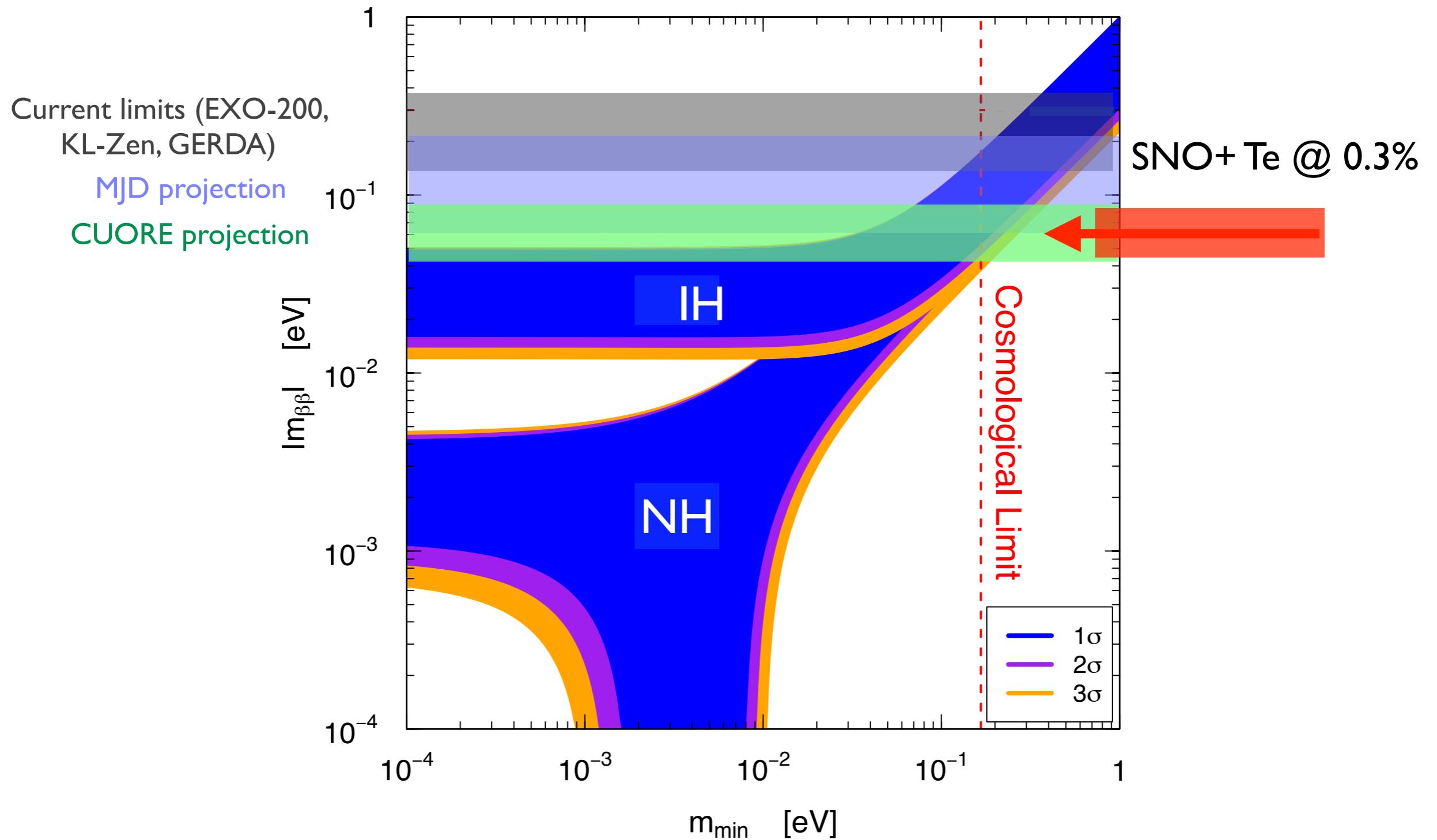
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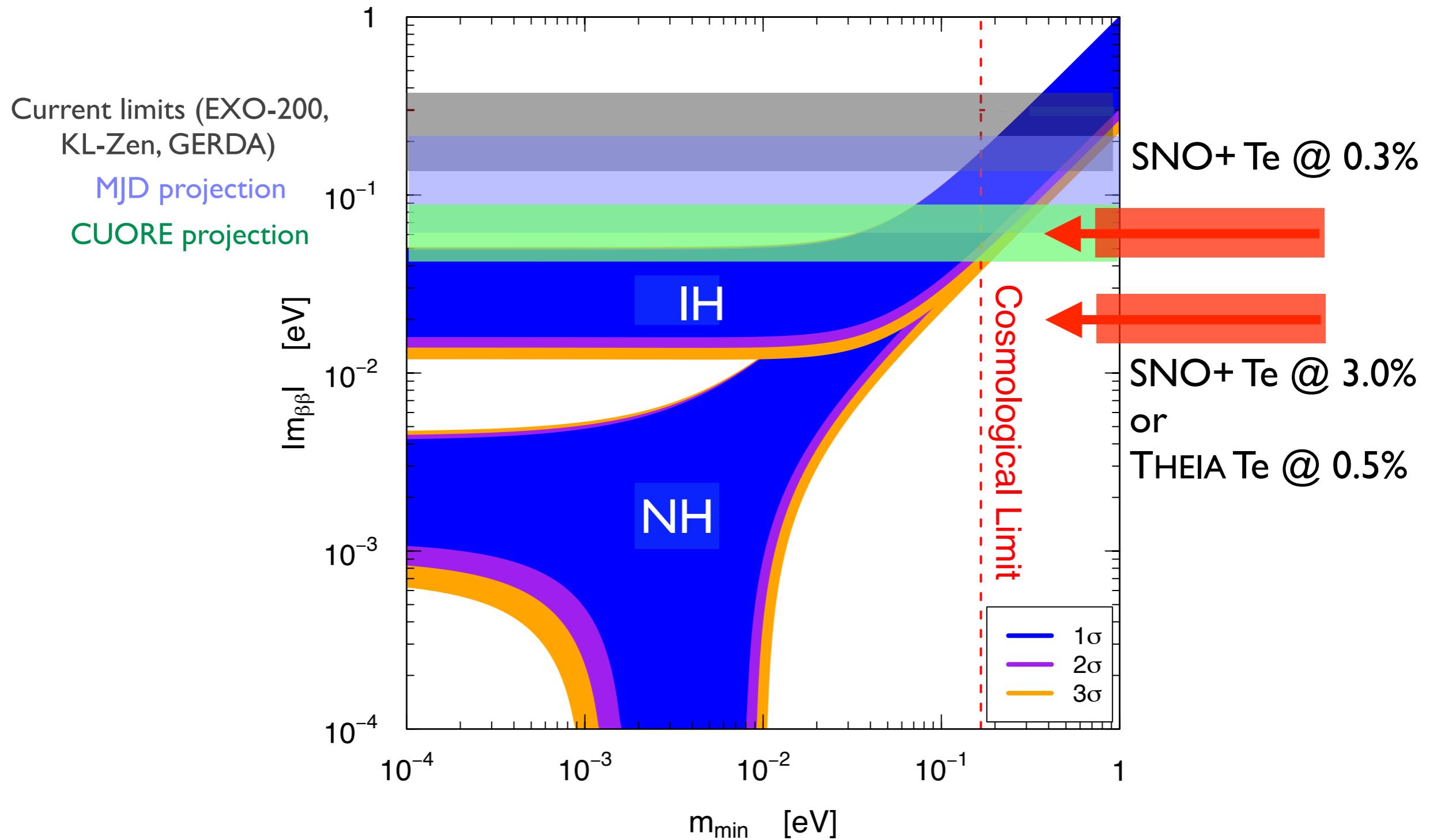
Future Plans: Probing the MH?



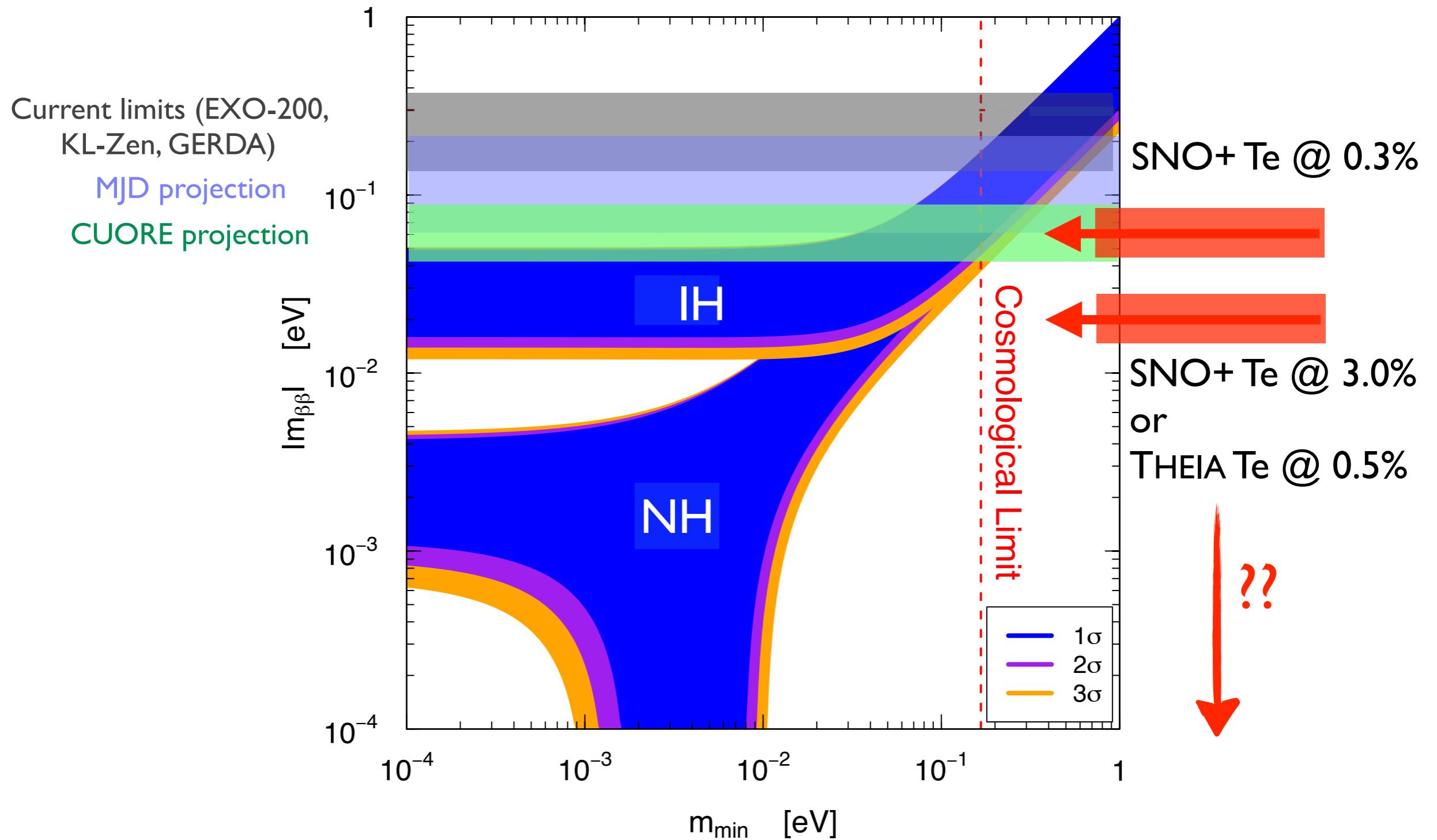
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Future Plans: Probing the MH?





Thank you

